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H. CLIVE BARNARD



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OUTLINES OF PHYSICAL GEOGRAPHY

BY

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CONTAINING 93 ILLUSTRATIONS
MAPS AND DIAGRAMS

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PREFACE

THIS little volume covers the physical groundwork of Geography as prescribed by the syllabuses of the Oxford and Cambridge Locals and similar examinations, and the book will therefore prove suitable for any pupils who have these tests in view. At the same time it should also be found useful for "classical" and other boys whose study of scientific subjects is necessarily limited. It affords a progressive course which should be applied in dealing with the various regions which are described in the ordinary school text-book of Geography.

It is hoped also that this book may provide a handy compendium of Physical Geography for those teachers who have specialized on purely literary subjects but who are interested in Geography and may be called upon to teach it.

An attempt has been made to render the majority of the questions which are appended to each section of the book, as far as possible *problems*; i.e., they demand from the pupil something more than a mere repetition of facts given in the text. In many cases also they form models from which the teacher can construct a large number of similar exercises.

The list of books and apparatus is not intended to be in any way exhaustive, but merely to give indications as to where and how the subjects touched upon in this introduction to Physical Geography may be more deeply studied.

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INTRODUCTION

THE word "physical" literally means "natural." Physical geography therefore is the name which has been given to that side of the subject which treats of inanimate nature. It deals, for example, with the shape, size, and movements of the earth, with the atmosphere, with climate, with the character of the earth's crust so far as it is known to us, and with the vast oceans which cover nearly three-quarters of the globe. But it leaves on one side such topics as trade, manufactures, the distribution of population, the position, growth, and importance of towns, the political divisions into which the world is split up; for all of these directly concern mankind. It even tends, as a rule, to pass over the distribution of vegetation and animals, because these are two forms of life and, as was said above, physical geography confines itself as far as possible to inanimate objects. Plant and animal geography therefore are usually regarded as separate branches of the subject, distinct from physical geography proper, and special treatises are devoted to them. Among the subjects which are taught in schools there are two groups which roughly correspond to the two sides of Geography. On the one hand we have what might be called *humanistic* subjects, such as history, the record of what man has done in the past, or literature and languages—men's thoughts and the manner in which these thoughts are expressed. On the other hand is a group of *scientific* subjects, such as chemistry or

physics, which deal with the world of nature as opposed to the activities of mankind. Geography forms a bridge between these two groups. It starts from scientific facts, and it is with these that physical geography is concerned. But at the same time it leads up to humanistic facts; it tries to explain how the natural conditions of the various regions of the earth affect the people who inhabit them. This second operation should doubtless be the chief aim of Geography; but we shall not attain it until we know something of the basis of scientific facts upon which Geography rests. It is for this reason then that the physical side of Geography must always be an essential part of the subject.

OUTLINES OF PHYSICAL GEOGRAPHY

PART I MAPS AND MAP-READING

Measurements.

IN order to obtain clear knowledge of any object in nature, measurement of some kind is almost always necessary. Thus in Geography we have to begin by the calculation of distances. We not only learn of the existence of various places ; we must find how far they are apart. Besides hearing of the position of mountains or oceans, we must know their height or depth. Hence the preliminary operations upon which Geography is based are those of measurement.

In early times, before exact measurements had been agreed upon or could be enforced, it was a little difficult to find a standard. One of the most obvious units of distance was the **pace**, for the distance between one place and another could easily be reckoned merely by counting steps. Sven Hedin, when exploring Tibet in recent years, actually employed this method because the inhabitants would not allow him to survey the ground. The ancient Romans used as their unit of measurement the thousand-paces or “mille passuum” ; the first part of this name has survived in our word **mile**. Another method was to take some part of the body as a convenient

measure. Thus we got the **foot**—the length from heel to toes, and the **ell**—originally the distance from the elbow to the tip of the middle finger.

But different people's paces vary considerably in size, and so do the lengths of their feet and forearms. Hence we usually find that as soon as a strong settled government is established in a country and trade has become important, there appears a set of measurements fixed and standardized. It is said that the size of the English **yard** was first taken from the length of Henry I's arm. A copy of this standard yard is now kept by a Government department (the Board of Trade), and a bar of metal of this length has been let into a wall on the north side of Trafalgar Square in London, where any one can refer to it. There are similar bars in other public places, and Government inspectors have been appointed whose duty it is to see that measures used by tradesmen correspond to the standards required by the State.

Measurements of length, such as the yard with its multiples (*e.g.* rod, furlong, mile, fathom) or submultiples (*e.g.* foot and inch) are based on a standard which was originally chosen more or less at random and then enforced by the State. But it is also possible to set up measurements which refer to some standard provided by nature; although when once determined they also become fixed by Government and are henceforth practically independent of their original source. Of this kind are the measurements of the **Metric System**, which are now used in most of the Continental European countries. The **metre** (= 39.37 inches), upon which this system is based, has been estimated as $\frac{1}{10000000}$ of a line drawn along the earth's surface from the Pole to the Equator. The English **geographical mile** is the length of a minute of the circle formed by the Equator. Since 60 minutes = 1 degree, and there are 360 degrees of

angular measurement in a circle, the geographical mile is $\frac{1}{60 \times 360} = \frac{1}{21600}$ part of the earth's circumference at the Equator. And since this circumference is estimated at 24,900 ordinary miles, the value of the geographical mile works out at roughly 1.15 ordinary miles.

This standard of measurement is used for calculating the rate at which a ship travels. In this case it is often called a **knot**. The instrument for estimating a ship's speed is known as a **log**. The simple form of this apparatus is going rapidly out of fashion nowadays; but since it explains terms which are still in common use, it will be well to describe it here. The old-fashioned log, then, consists of a quadrant of

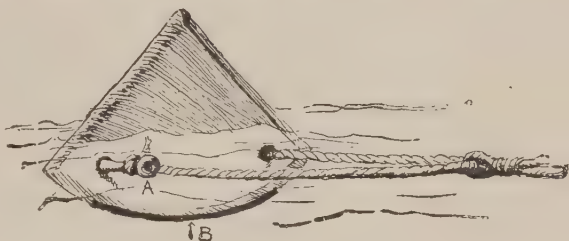


FIG. 1. *A Log-ship.*

A is a bone peg. After the speed of the ship has been taken, the log-line is jerked smartly. This causes the peg to come out and the log-ship is hauled in edgewise. It thus offers less resistance to the water than if it were pulled face foremost.

wood, about $\frac{1}{2}$ inch thick, and weighted with lead along its curved edge (B). When placed in the water, this quadrant (which is usually called the "log-ship") floats with its point upwards. To one of its faces a long line is attached, and this line at its other end is wound over a log-reel. To heave the log, a sailor used to hold the reel over his head while an officer threw the log-ship from the stern of the vessel. Owing to the resistance of the water against the face of the wooden quadrant, this tended to remain in the place where it first entered the water; it was thus prevented from being dragged after the ship. At the same time the log-line ran out owing to the forward

movement of the vessel. This line was divided into a number of equal parts, each marked by a knot. At the moment when the log was heaved, a log-glass (similar to a small hour-glass or an egg-boiling glass) was turned. The size of this glass and the distance between the knots on the log-line was so arranged that by counting the number of knots paid out while the log-glass was running one could tell the number of geographical miles travelled by the ship in one hour. If, for example, the glass ran for $\frac{1}{2}$ minute (*i.e.* $\frac{1}{120}$ of an hour), the knots on the log-line would have to be placed at intervals of $\frac{1}{120}$ part of a geographical mile—*i.e.* roughly 50 feet; and thus, if 15 of them passed out during the $\frac{1}{2}$ minute, the ship's speed would be 15 *knots*. Naturally this method is not an exact one, for we cannot be sure that the log-ship will remain throughout the operation in precisely the same place.* Various patent logs have been invented and are now in very general use; by means of some of them it is possible to read off the speed of a ship on a dial which is fixed to the taffrail.

Scale.

We say that a map is drawn to **scale** when a given measurement on the map represents a much larger measurement in nature. Thus an inch on the map may perhaps stand for 500 miles of actual distance; or, in the case of a plan of some small area, 1 inch may represent as little as $\frac{1}{6}$ of a mile or even less. If the lengths on the map are relatively small compared with the distances for which they stand, we say that the map is on a small scale; if the opposite is the case, we speak of a large scale map. A map of Asia in an atlas

* In actual practice nowadays, when the old-fashioned hand-log is still employed, a watch is used instead of the sand-glass and the line is wound on a reel fitted with a brake.

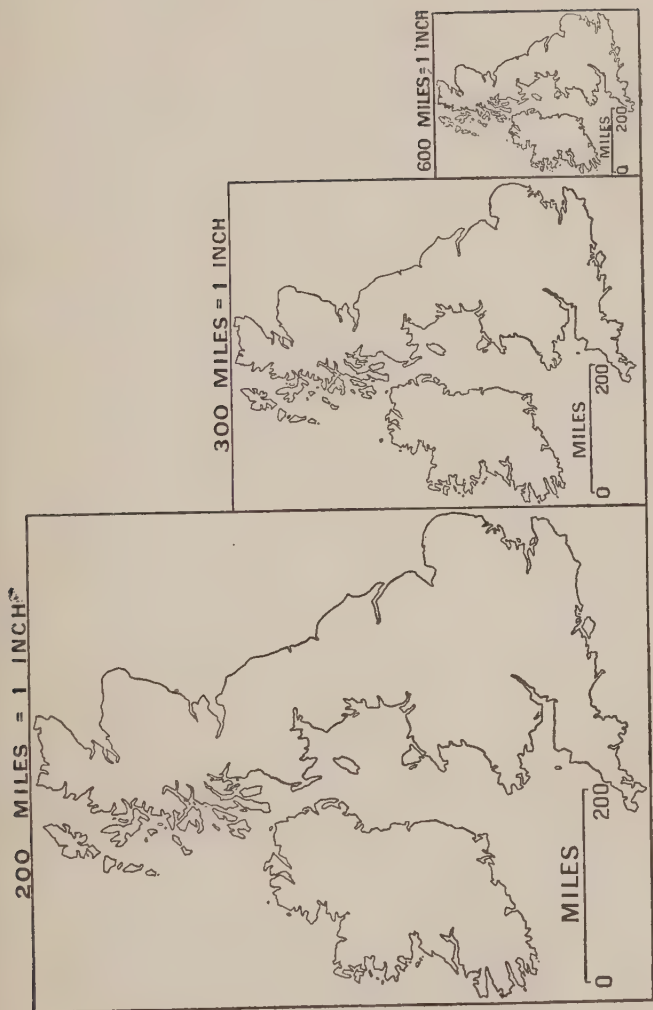


FIG. 2. Outline maps of the British Isles on three different scales.

would be a good example of the former, and a map of an English parish of the latter. It is obvious (*see* Fig. 2) that a plan or map can be drawn correctly to any given scale; for example, 1 inch may stand for any number of miles or yards. But the scale adopted in each case must always be inserted in one corner of the map. By this means it is possible to ascertain the actual distance between any two places which are shown; all one has to do is to measure this in inches and then refer to the scale.

As will be shown presently, it is comparatively easy to make a plan to scale of a room or a playing field; but many careful and difficult observations must be taken in order to construct a map, correctly drawn to scale, of a large land area. There is in this country a Government department—the **Ordnance Survey**—which devotes its attention to the preparation of very accurate maps. Fig. 3 is reproduced from the Ordnance Survey map of the Buttermere district in Cumberland. As the scale in the corner shows us, 1 inch on the map represents a mile—in other words, the map is on the scale of 1 inch to the mile. The distance between any two points on the map is $\frac{1}{63360}$ of the actual distance, since there are 63,360 inches in a mile. The fraction which denotes the proportion between measurements on the map and measurements in nature is called the **representative fraction**; and this is often denoted by the initials R.F.

Relative Position.

It is obvious that a map must do something more than show the distance between one place and another. It must also give their relative positions. This involves an idea of direction. In ordinary life and in a civilized country where travellers rarely stray from the roads,



Reproduced from the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office.

FIG. 3. Part of an Ordnance Survey Map of the Buttermere District, Cumberland.

There is a picture on page 117 of the country represented in this map.

we can confine direction to the two terms "left" and "right." But these expressions are not precise; they vary with the position of the person who uses them. Hence it has been found necessary to fix precise points which never vary and by reference to which we can fix correctly the relative positions of the various objects which are shown on a map. These points—North, South, East, and West—are usually known as the **Cardinal Points** or **Points of the Compass**; they can be determined by reference (a) to the Sun; (b) to the Pole Star; (c) to the Mariner's Compass.

(a) *The Cardinal Points as determined by the Sun.*

During the day-time the Sun appears to move gradually through the heavens, describing a great curve as it does so. When it is low in the sky—i.e. when it is near its rising or setting—it casts long shadows; but there is a time when it reaches the highest point in its course and when, therefore, the shadows which it casts are at their shortest. This always occurs about 12 o'clock noon. If we can determine the exact instant when the sun is at its highest and casts its shortest shadows, we may know that it lies due South of us.* For practical purposes we may say that the sun is almost due south at noon, and when the south is discovered it is easy to find the other cardinal points. A line, drawn along the shadow of an upright pole at the moment when the sun is at its highest, would run due north and south towards the two poles. Such a line is called a **meridian**, for the Latin word *meridies* means "midday."

It is sometimes said that the sun rises in the east and sets in the west. This is not strictly true. On the longest day (June 21) the sun with us rises towards the

* This is universally true only in places which are between the Tropic of Cancer and the Arctic Circle (see page 45).

N.E. and sets near the N.W., and reaches the highest point which it ever attains at noon on this day. But on December 21, the shortest day, it rises near the S.E. and sets roughly S.W. Twice in the year (March 21 and September 22) it rises almost due east and sets almost due west. Thus its place of rising swings from S.E. to N.E. during the first half of the year and from N.E. to S.E. during the latter half; similarly, the place of setting swings first from S.W. to N.W. and then from N.W. to S.W. But the sun's position at noon is always

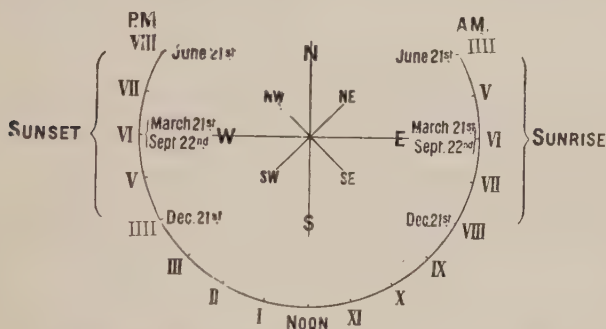


FIG. 4. Diagram to show the length of daylight and the direction of the sun at any given time.

This diagram holds good for places in the latitude of London.

practically due S. In summer-time the hours of daylight are more numerous than in the winter. The reason is that the sun describes a longer path through the sky in summer than in winter. Refer to Fig. 4.

(b) The Cardinal Points as determined by the Pole Star.

To discover the Pole Star look for a group of stars known as the Plough or Charles's Wain, or the Great Bear (*Ursa Major*). The shape of this constellation is shown in Fig. 5. At one end of it are two stars known

as the Pointers (α , β), because they point to the Pole Star. The Great Bear, like all the other constellations, appears night by night to revolve round a fixed spot in the heavens, and almost exactly on this spot the Pole



FIG. 5. How to find the Pole Star.

Star is situated. Thus it alone never changes its place in the sky. The Pole Star is situated directly above the north pole of the earth and so, by looking towards this star, we can at once determine the northward direction. This method of obtaining the cardinal points is even more easy than by reference to the sun; for the sun gives us the south only at midday, whereas

the Pole Star shows us the north at any time when it is visible.

(c) *The Cardinal Points as determined by the Mariner's Compass.*

If an ordinary bar of steel be balanced on an upright pivot it may be made to stay in any desired position. But if the steel bar be magnetized, one end of it will persistently point northwards and the other southwards. This property of the magnetic or mariner's compass was probably well known to the Chinese long before it was used in Europe, and it appears not to have been introduced into this part of the world until the twelfth century A.D. at the earliest.

Careful investigation of the magnetic needle will reveal the fact that in this country it does not point exactly

north, but in a direction somewhat westward of north. This divergence from the true N. and S. direction is known as the **variation** or **declination** of the compass. The exact amount of variation gradually changes from year to year ; it also differs in different parts of the earth and is liable to be effected by electric storms and other local disturbances.

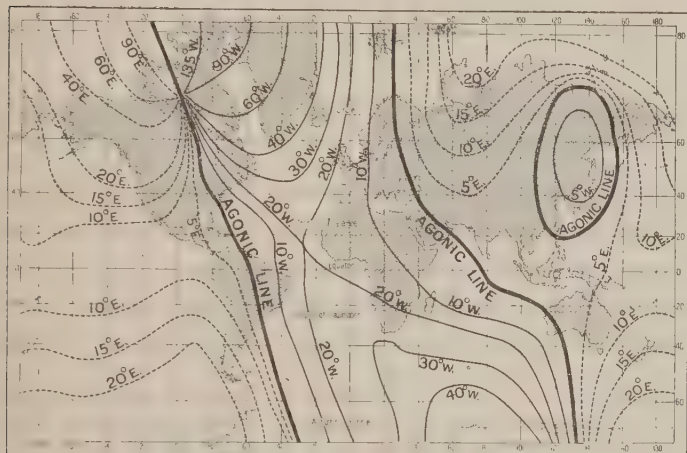


FIG. 6. *Map of Isogonic Lines.*

These lines are drawn through places which have the same amount of variation. Along the *agonic* lines the compass needle points due N. and S.

In 1657 the compass in London pointed due N. and S. ; prior to that year variation had been eastward, but it then crossed over to the west, and increased until 1816 when it was $24\frac{1}{2}^{\circ}$ W. of N. Since that time it has been growing gradually less and at the present day in London it amounts to about 16° W. For the amount of variation in different parts of the world at the present time, refer to Fig. 6

In spite of its variation, the mariner's compass affords

the easiest way of discovering the cardinal points. A ship's compass usually consists of one or more magnetized needles which are carefully pivoted in the middle of a copper bowl fitted with a glass lid. A compass card

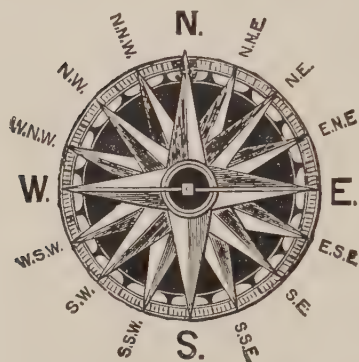


FIG. 7. A Compass Card.

is fixed to the needles so that they all move together, but in smaller compasses the needle is usually free. It is of course necessary to make the proper correction for variation.

Surveying and Map-Making.

The making of exact and detailed maps, such as are shown in our atlases, necessitates complicated instruments and highly skilled surveyors. But it is possible by various simple methods to construct sketch-maps of small areas; and exercises of this kind form part of what is sometimes called "practical geography."

Offsets.

One of the easiest methods of surveying involves the use of an instrument called the **optical square**,* which contains a small piece of glass, one part of which is transparent and the other silvered, so as to act as a mirror. Now suppose a base line *XY* and a number of objects, *a, b, c, d*, &c., at various points on either side of it. The surveyor starts from *X*, and, looking into the optical square, sights *Y* through the unsilvered part of the glass. He then walks along the base line until, on reaching a

* The "Anglemetre" (see p. 150) can be used as an optical square.

point Z , the reflection of a appears in the mirror exactly over the direct image of Y . The optical square is so constructed that the angle XZa is a right angle. If then XZ and Za be measured they can be plotted on a map, and similarly the positions of b , c , d , &c., with

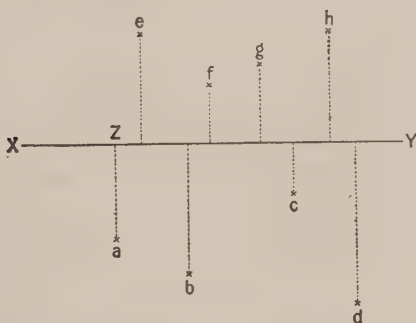


FIG. 8. *Diagram to illustrate surveying by offsets.*

reference to XY can be ascertained. These lines drawn at right angles to the base line are known as **offsets**.

The Plane-Table.

Surveying by means of offsets can be employed only when the distance between every point can be measured. But it often happens that we must plot inaccessible objects on our maps. In such cases a **plane-table** can be used. This consists of a drawing-board mounted on a tripod. A spirit-level is provided so that the board can be set up in an exactly horizontal position; and it can also be made to revolve horizontally on a pivot, if required.

A base line AB is first measured out and on a piece of paper affixed to the drawing-board a point a is marked, corresponding to A . The surveyor now sets up his plane-table at A , levels it, and taking a flat heavy graduated

ruler fitted at each end with sights, places one end of it on *a*, and turns the drawing board until B comes into view through the sights. He then draws a line *a b* along the edge of the ruler (or **alidade** as it is sometimes called); and he makes *a b* represent A B on some convenient scale. Next, with the help of the alidade, he

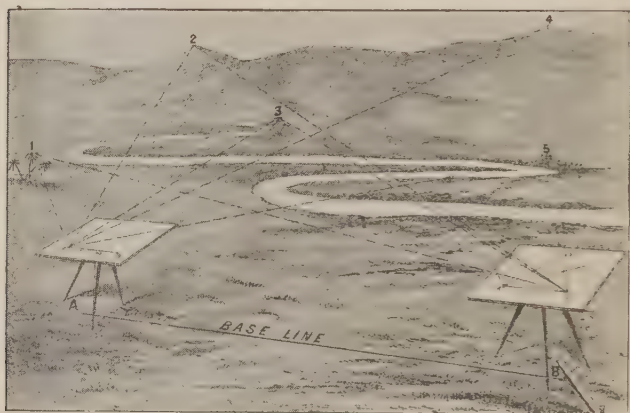


FIG. 9. *How to use the Plane-Table.*

N.B.—There is an *alidade* under the plane-table at B.

sights a number of distant objects (1, 2, 3, 4, 5, &c.) and draws lines from *a*, in the direction of them. This done, the surveyor moves his plane-table to B, levels it, and places *b a* in exact alignment with B A. The distant objects, 1, 2, 3, 4, 5, &c., are once more sighted—this time from B—and lines drawn towards them. The points where these new lines cut those which were drawn from A will give the position of the distant objects in relation to the base line (*see* Fig. 9).

The Theodolite.

A more accurate surveying instrument is the **theodolite**. It consists essentially of a telescope which is

mounted on a stand and pivoted so as to revolve both vertically and horizontally. The exact amount of angular movement in each case can be read off on a scale.* The telescope can be clamped in any position. A spirit-level is fixed to the telescope, and a compass is also necessary; by these means the telescope can be set in a horizontal and a north-and-south position, and its subsequent angular movements calculated from these starting-points. Suppose that the telescope is set so that it coincides with a N. and S. base line and that it is then turned horizontally until an object N.W. of the theodolite comes into view. A line drawn from this object to the instrument would give an angle of 45° with the base line, and this angle can be read off on the horizontal scale of the theodolite. Similarly, an object due E. of the instrument would give an angle of 90° with the base line. Angles obtained in this way by reference to a N. and S. base line are called **azimuths**. In the two cases just given, the azimuth of the first object will be 45° W., and of the second 90° E. The azimuth of a point S.W. of the observer would be 135° W. If a number of angles of this kind are obtained from either end of an accurately measured base line a map

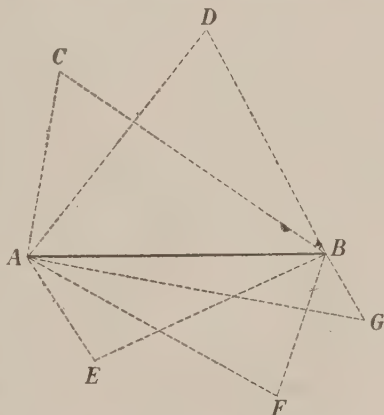


FIG. 10. *Diagram to illustrate Triangulation.*

* A modified form of theodolite called the *dumpy level* is much used for surveys. It can be moved horizontally only, and thus can measure horizontal, but not vertical, angles.

can be constructed with the help of a protractor and a graduated ruler. As in the case of the plane-table survey, the position of a given object with reference to the base line will be denoted by the point of intersection of the lines drawn from either end of the base line towards that object. This system of surveying is known as **triangulation**. Refer to Fig. 10.

When triangulation is impossible owing to the character

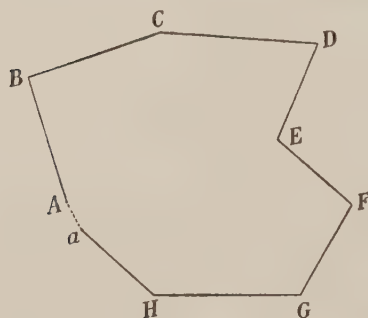


FIG. 11. *Diagram to illustrate Traversing.*

of the country, another method, known as **traversing**, is often employed. Suppose that B is visible from A, C from B, D from C, and so on, but not C from A, D from B, &c. The azimuth of B is first taken from A, and the distance from A to B is then measured; the position of B is thus discovered. In the same way

the position of C is found from B, that of D from C, and so on, until the survey is completed with the observation of A from some other point (H). It may happen that this last operation gives the surveyor on his map not A, but some point (a) near to it. a A is then called the **closing error** of the survey and the points B, C, D, E, F, G, H, are all slightly adjusted so as to compensate for this error.

The theodolite is also useful for ascertaining slopes and heights. One of the simplest methods is that which is illustrated in Fig. 12 and needs no further explanation. Another method (Fig. 13) is to take a base line A B, which is carefully measured. At either end of it the theodolite is first levelled and then definite points, C, D, E

are sighted. Thus the angles, CAB , CBA , DAB , DBA , &c., are obtained. From the triangles thus formed the vertical heights CC' , DD' , EE' , can be ascertained, due allowance being made for the height



FIG. 12. *How to use the Theodolite in determining heights*

Suppose the telescope to be five feet above the ground. If then it is levelled, the point B will be five feet higher than A, and similarly C will be five feet higher than B.

of the theodolite above the ground. The angular distance of a point above the horizon is called its **altitude**. Thus the altitude of the point C, as calculated from A,

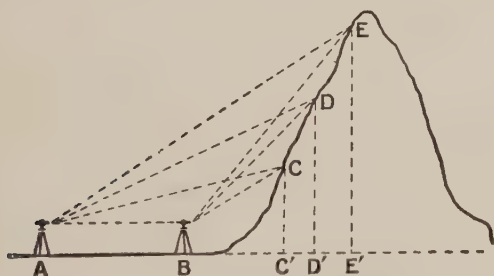


FIG. 13. *Another method of determining heights.*

is the size of the angle CAB . Notice that the direction and position of any distant object with reference to an observer can be accurately shown by giving its azimuth and altitude. This method is therefore often employed for locating heavenly bodies.

Representation of Relief.

Hitherto we have considered maps chiefly as regards their functions in indicating distance and position. But there still remains a fact of great importance if we are to have a clear idea of the various parts of the earth's surface. We must know something of the **relief** of land masses and the ocean bed—*i.e.* we must have some information as to heights and depths. A map which shows this is sometimes called a **physical map**.

On early maps the only way of indicating mountains was by inserting small pictures of them. In order to show a range, a number of separate peaks were drawn close together, and out of this system originated the caterpillar-like representations of mountains which are still found in some atlases. A more elaborate system of this kind consists of drawing hill-shading lines called **hachures**. If the slope is steep the hachures are drawn in thick lines and close together; if it is gradual the hachures are lighter and further apart. The general effect of a hachured map, if looked at from a little distance, is not unlike a photograph of a model, such as the "relief maps," which are given in some atlases. Very beautiful and useful maps of this kind have often been prepared, but the great objection to them is that they merely show that one place is higher than another; they give us no exact information as to how much higher. For instance, the brink of the Western Ghats has to be shown in much the same way as the wall of the Himalayas.

Another method of representing heights is by the use of **contours**. These are lines drawn on a map through places which are all of exactly the same height. For example, if the sea were to rise 600 feet, its edge would form a contour round the land and would coincide with the 600 feet contour on our present maps. As a matter

of fact, the coast-line itself is really a contour. If the contours are far apart the slope is gradual; if they are close together there is a steep ascent. Suppose, for instance, the distance between the 500 feet and 600 feet contours is 100 yards (300 feet), then we know that in traversing 300 feet of distance we have ascended 100 feet of height—*i.e.*, a steep gradient of 1 in 3. But if the distance between the two contours is shown as 1500 yards (4500 feet), the gradient will be much more gradual—only 1 in 45. This will perhaps become clearer after reading p. 23. The difference of level between two adjacent contours is called the **vertical interval**, and is usually denoted by the initials V. I. It should be noticed that contours cannot possibly cross one another and are at right angles to hachures.

The earliest contoured maps were charts; it is obviously far easier to let down a sounding line and so ascertain sea-depths than to take the more elaborate observations which are necessary before we can discover heights above sea-level. It is not unusual, especially in relief maps of large land areas, to colour the spaces between the contours, shades of green usually being employed for the low ground and shades of brown for the heights, while for the sea-depths shades of blue are used. These bands of colour are called **layers**. Perhaps it is hardly necessary to point out that the green tints on a contoured map have no relation to the type of vegetation which is often found on lowlands. However, to avoid any possibility of confusion, some of the best layered maps of to-day use shades of one colour only for the land—varying, for example, from pale yellow to dark brown. It should be borne in mind that the contours and the colouring of the layers may vary greatly on different maps.

The following are two typical examples of the schemes which may be adopted :

PHYSICAL MAP OF ENGLAND AND WALES

(From Philip's *New School Atlas of Comparative Geography*)

<i>Land</i>	over 3,000 ft.	black
<i>Heights</i>	1,800-3,000 ft.	dark brown
	1,200-1,800 ft.	brown
	600-1,200 ft.	light brown
	300- 600 ft.	light green
	0- 300 ft.	green
<i>Sea</i>	0- 300 ft.	light blue
<i>Depths</i>	below 300 ft.	blue

PHYSICAL MAP OF INDIA

(From Holdich's "India"—*Regions of the World Series*—Oxf. Univ. Press)

<i>Land</i>	over 24,000 ft.	black
<i>Heights</i>	16,000-24,000 ft.	greenish brown
	12,000-16,000 ft.	purple brown
	6,000-12,000 ft.	red brown
	3,000- 6,000 ft.	brown
	1,500- 3,000 ft.	light brown
	600- 1,500 ft.	light green
	0- 600 ft.	green
<i>Sea</i>	0- 600 ft.	white
<i>Depths</i>	600- 3,000 ft.	light blue
	3,000- 6,000 ft.	blue
	6,000-12,000 ft.	dark blue
	12,000-18,000 ft.	slate blue
	below 18,000 ft.	greenish blue

Sometimes sea-depths are indicated in fathoms, the fathom being equivalent to 6 feet. The system of colouring or shading which has been adopted in any map is always shown by a key in one corner of it.

It is clear that contours and layers give far more precise information as to heights than do hachures. None the less, the contour method is not without its disadvantages. To begin with, layered maps may encourage a false idea that the land is built up in a series of

terraces ; and this danger should be carefully borne in mind. Then again, suppose that contours were inserted on a map at intervals of 500 feet, and that in one place there was a steep brink rising from 50 feet to 490 feet. This would be shown by the shading on a hachured map, but the contours would fail to indicate the steep ascent. There are several remedies. We might insert the figures 490 on the map at the spot where the ground reached this altitude. Exact heights of this kind have, in point of fact, been ascertained in many parts of our islands, and they are inserted in figures between the contours on Ordnance Survey maps. These spots are marked by a **benchmark** in the form of a broad arrow ($\nearrow$) cut in some convenient place, and they are indicated on the 6 inches to the mile Ordnance Survey maps by the letters B.M. Thus " B.M. 568 $\nearrow$ " marks a spot the height of which above sea-level has been ascertained to be 568 feet. But this method can be employed only to a limited extent ; for, in a map which contains many names, the insertion of figures indicating heights would soon lead to confusion. Another remedy would be to insert contours at more frequent intervals. But this involves even greater complexity, especially if layers are also employed ; because the more numerous the shades of colour inserted the less easy are they to distinguish and the more expensive is the map to produce. The best solution of the difficulty is to combine contours with finely-drawn hachures. This method is adopted in the best modern wall-maps and is also illustrated by the Ordnance map, which is reproduced on p. 7.

Ordnance Map Symbols.

On the 1-inch-to-the-mile maps prepared by the Government Ordnance Survey, the following conventional signs are used :

1 Inch Scale :

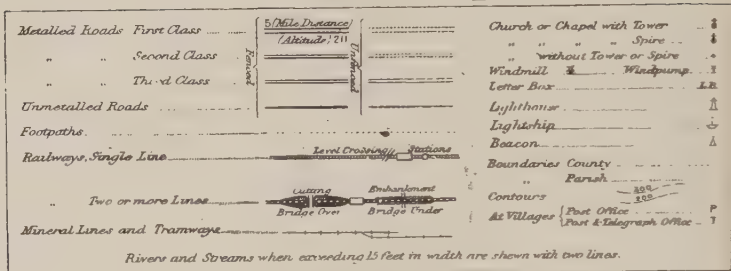


FIG. 14. Ordnance Map Characteristics.

Sections.

From a contoured map it is possible to make a **section** (which is really a kind of graph) along any line drawn across the map. Suppose it is required to draw a section along a line joining two given points, A and B, on a con-

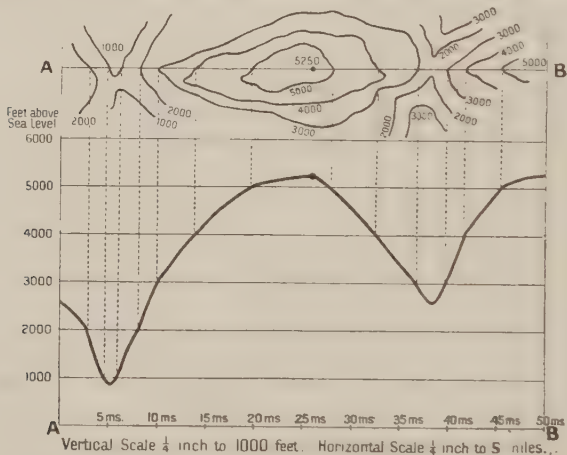


FIG. 15. A section obtained from a Contoured Map.

toured map (see the upper part of Fig. 15). First ascertain the length in miles or degrees along the line A B,

and decide the scale of distance which will be most convenient to adopt. If A B is 50 miles long a scale of $\frac{1}{4}$ inch to 5 miles would give us a base line on our paper $2\frac{1}{2}$ inches long. Next discover the highest point along A B and decide a suitable vertical scale; if this highest point is 5250 feet above sea-level we might adopt a scale of $\frac{1}{4}$ inch to 1000 feet; an upright line $1\frac{1}{2}$ inches long would then represent 6000 feet and so leave plenty of room in which to show the 5250 feet elevation. All the points where A B crosses the contours on the map are now plotted on the diagram and through these points a freehand curve is drawn (*see* Fig. 15). The result will be the required section.

It is obvious that the proportion between the height and breadth of the section will be much exaggerated. In the former case $\frac{1}{4}$ inch represented 1000 feet, in the latter 5 miles (26,400 feet); so that our section is 26.4 times higher in proportion to its breadth than would be the case if the vertical and horizontal scales were the same. But without some such exaggeration the surface of the land as shown in a section would appear practically flat. If then this exaggeration is borne in mind a section may be very useful in giving some idea of the lie of a country or the gradients of a road. But we must always be carefully on our guard against mistaking these purposely exaggerated sections for properly proportioned diagrams.

PROBLEMS AND EXERCISES

1. " 'Knots per hour' is bad English and worse mathematics." Explain this statement.

2. Find the Representative Fractions of maps constructed upon the following scales:

(a) 1 in. to $\frac{1}{8}$ mile; (b) 1 in. to 12 miles; (c) 1 in. to 400 miles; (d) 1 in. to 1000 miles; (e) 25.344 inches to 1 mile.

3. Find the Scales which correspond to the following Representative Fractions :

$$(a) \frac{1}{26720}; \quad (b) \frac{1}{63360000}; \quad (c) \frac{1}{158400000}; \quad (d) \frac{1}{5000};$$

$$(e) \frac{1}{10000000}; \quad (f) \frac{1}{30000000}.$$

4. Construct a plan from the following data :

Base line A H runs due S. to N.

(Capital letters represent distances along the base line ; small letters represent objects to which offsets are drawn).

<i>Base line</i> : AB = 100 yds.	<i>Offsets</i> : Ba = 120 yds. (west)
BC = 230 yds.	Cb = 300 yds. (east)
CD = 85 yds.	Dc = 180 yds. (west)
DE = 115 yds.	Ed = 315 yds. (east)
EF = 60 yds.	Fe = 90 yds. (west)
FG = 105 yds.	Gf = 190 yds. (east)
GH = 175 yds.	

What is the distance from A to d and from b to e ?

5. With the help of a protractor and a ruler, make a plan from the following data which have been obtained by triangulation :

Base line X Y (north end X, south end Y) = 100 yds.

From X :

Azimuth of a is	80° W.
„ „ b „	110° W.
„ „ c „	150° W.
„ „ d „	145° W.
„ „ e „	90° E.
„ „ f „	120° E.
„ „ g „	170° E.
„ „ h „	135° E.

From Y :

Azimuth of a is	30° W.
„ „ b „	35° W.
„ „ c „	40° W.
„ „ d „	70° W.
„ „ e „	40° E.
„ „ f „	45° E.
„ „ g „	60° E.
„ „ h „	65° E.

What is the distance from X to e and from c to g ?

6. With the help of a protractor and a ruler, make a plan from the following data which have been obtained by traversing :

Azimuth of B from A is 45° E.				Distance from A to B is 100 yds.			
"	"	C	"	B	"	95 $^{\circ}$ E.	" " B " C " 220 yds.
"	"	D	"	C	"	120 $^{\circ}$ E.	" " C " D " 180 yds.
"	"	E	"	D	"	170 $^{\circ}$ W.	" " D " E " 150 yds.
"	"	F	"	E	"	100 $^{\circ}$ W.	" " E " F " 120 yds.
"	"	G	"	F	"	80 $^{\circ}$ W.	" " F " G " 200 yds.

What is the azimuth of A from G ?

What ought the distance from G to A to be ?

How far is it from B to E ?

7. Make a survey of the school playground or playing field. Reproduce your plan on a different scale.

8. The altitude of the top of a tower as obtained by a theodolite from a point A is 40° and from a point B 60° . The length of the base line A B is 40 feet and the height of the theodolite above it 5 feet. What is the height of the tower above the base line ?

9. Draw a sketch map showing a piece of main road which crosses a meadow (road unfenced on both sides), then passes over a stream by means of a bridge, next goes through a wood (where both sides are fenced), and on coming out of the wood passes under a railway bridge. The railway crosses the road at right angles, on an embankment.

N.B.—Use the conventional signs employed in the maps of the Ordnance Survey. (Oxf. Jun. Local, 1906.)

10. A church (with a spire) stands on the top of a conical hill, the hilltop being 500 feet above sea-level. A mile to the south of the church a rapid stream flows westwards about 200 feet below. The road from the church crosses the stream by a bridge about two miles to the south-east of the church.

Draw a rough sketch map representing the piece of country described, on a scale of about 2 inches to a mile. Use the signs employed on Ordnance maps and insert contours at intervals of 50 feet. (Oxf. Jun. Local, 1908.)

11. Try to find some benchmarks in the neighbourhood

of your school. Ascertain their height above sea-level by reference to an Ordnance map of the district.

12. Draw a section from Bombay to Lhasa.

13. Draw a section across Africa along the equator.

14. Make a diagram to show the comparative heights of Mt. Everest, Mont Blanc, Snowdon, and some other mountain or hill which you have climbed or seen.

PART II

THE EARTH AS A GLOBE

The Shape of the Earth.

IF we merely trusted unthinkingly to the evidence of our eyes we should probably decide that the earth is a flat plain ; for a long time, indeed, every one was quite content to hold this opinion. The earth was usually regarded as a flat plate of land, surrounded by the great river Oceanus, but it was sometimes said to be a cylinder or even a cube. As early, however, as the sixth century B.C. a Greek philosopher, named Pythagoras, is said to have put forward the theory that the earth is a sphere ; and although few people believed it either then or for centuries afterwards, we now know that it is the truth. The following are the chief methods by which we can establish this fact :

(a) *By Circumnavigation.*

In 1519–1522 a Spanish expedition under Magellan sailed westwards round the southern extremity of South America, across the Pacific, and home past the Cape of Good Hope. This first **circumnavigation** of the world showed that it is possible for a ship sailing constantly in the same general direction to return to the point from which she set out. Since Magellan's time the world has been frequently circumnavigated both from W. to E. and from E. to W. ; and although this does not of itself

prove that the earth is a globe, it does show that we are not living on a cube or on a vast level plate.

(b) *By the disappearance of ships at sea.*

As a ship leaves the shore she appears to grow smaller and smaller in size as she sails towards the horizon. At last she stands up on the horizon (B) and then begins to disappear, hull first, until only her masts are visible (C)

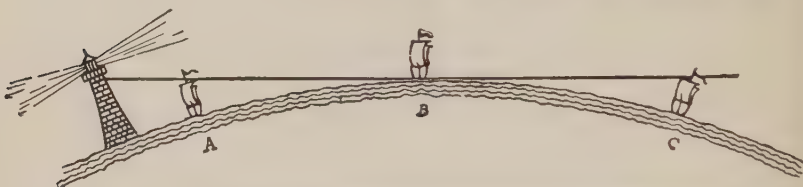


FIG. 16. *Diagram to illustrate the disappearance of ships at sea.*

N.B. The proportion between curve of the surface and the height of the lighthouse is, of course, greatly exaggerated.

Finally she sinks from sight. Such a phenomenon would be quite impossible on a flat plane; and since these appearances are found in all parts of the ocean and in any direction, we must conclude that the earth's surface is curved. And since the amount of curvature is everywhere roughly the same, the earth is obviously a globe.

(c) *By the distance of the horizon.*

If one takes up a position in a flat plain where there is nothing to obstruct the view or on a boat in mid-ocean, the horizon appears as a huge circle, at the centre of which the observer stands. But if the observer rises from this point of view (*e.g.*) by climbing a tower or a mast or ascending in a balloon, the distance of the horizon increases (the formula for ascertaining the relation of height to the distance of the horizon is $\sqrt{1\frac{1}{2} \times \text{height in feet}} = \text{distance of horizon in miles}$). But unless the view is obstructed

the horizon remains circular—*i.e.* every point upon it is at an equal distance from the observer. This fact again is found to hold good in every part of the world where the experiment can be tried. Now a sphere is the only solid from any point on the surface of which a circular horizon can be obtained. This then again proves the true shape of the earth.

(d) By the Bedford Level experiment.

This experiment was carried out in the very flat fen district known as the Bedford Level. By the side of a straight stretch of river here three posts, A, B, and C, were set up at distances of 3 miles apart; they

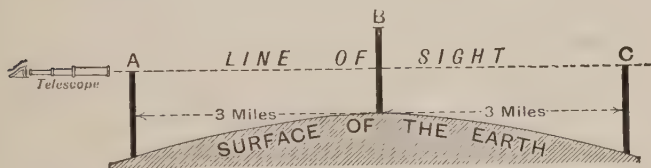


FIG. 17. Diagram to illustrate the Bedford Level experiment.

were all of exactly the same height (13 feet 4 inches) above the surface of the water. Upon sighting the point C from the point A with a telescope, it was found that the middle post projected nearly 6 feet above the line of sight. This, of course, was due to the curvature of the earth's surface; and from the arc given by the amount of curvature in the distance surveyed, it was possible to calculate the size of the whole circumference of the earth.

(e) By the earth's shadow during an eclipse of the moon.

It sometimes happens that the earth comes between the sun and the moon and so causes an eclipse of the latter. Under such conditions a shadow of the earth is cast upon the moon and the edge of this shadow is

invariably a curved line. This, of course, helps to show that the earth is a sphere. It is said that this proof was first put forward by the great Greek philosopher Aristotle, who flourished about the middle of the fourth century B.C. Notice also that all the chief heavenly bodies, so far as we know, are spheres, and it would be very curious if the earth alone among them had some other form.

(f) *By the altitude of the Pole Star.*

If we look at the sky on a clear starlight night we might well imagine that this earth of ours is situated at

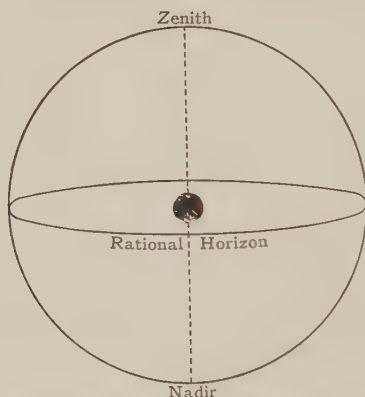


FIG. 18. *Diagram to show the Celestial Sphere with the earth at its centre.*

N.B.—The zenith, nadir, and rational horizon are here calculated from the North Pole of the earth.

the centre of a great celestial sphere of which only half is visible to us from any given spot on the earth's surface. The point in the heavens immediately above our heads is called the **zenith** of the place where we are standing; a similar point beneath our feet in the sky on the other side of the globe is the **nadir** of this place. A line joining

zenith and nadir would pass through the centre of the earth and its direction would be indicated by a plumb-line. We can also imagine a great plane, such as is shown in Fig. 18, also passing through the centre of the earth at right angles to the zenith-nadir line. It cuts the celestial sphere into two halves, and the line along which it does so is called the **true** or **rational horizon*** of the place from which the zenith was originally obtained. Notice that every spot on the earth's surface has its own zenith, nadir, and rational horizon.

Almost exactly at the zenith of the North Pole of the earth is the Pole Star. (*N.B.*—This star is at the nadir of the South Pole of the earth.) But if one moves southwards from the Pole towards the Equator, the Pole Star will gradually sink from the zenith. At the Equator itself the Pole Star will appear on the rational horizon, and south of the Equator it will not be visible at all. These facts show that the earth's surface is curved in a north and south direction.

Very precise observations have tended to prove that the earth is not exactly a sphere, but what is called an **oblate spheroid**—a globe which is slightly flattened at the Poles. It is said that the polar diameter is 41,710,242 feet (nearly 7900 miles) and the equatorial diameter 41,852,124 feet (about 7926 miles). If this be so, the latter is roughly $\frac{1}{306}$ longer than the former. When represented on a 12-inch globe (the usual size of a school globe), the difference between the two diameters would amount to only $\frac{1}{25}$ inch. Thus the polar flattening of the globe is for our purpose a negligible quantity; and to

* This use of the term "horizon" must not be confused with its ordinary sense, as employed (*e.g.*) on p. 28. In the latter case, for the sake of distinction, the expression *visible* or *apparent horizon* is sometimes used.

compare the shape of the earth to that of an orange, as is sometimes done, may give a totally wrong impression.

Relative Position on the Globe.

Having once proved that the earth is a globe, we must discover some means of fixing the position of places upon it. In order to do this we imagine a number of lines to be traced upon its surface. Some of these run eastwards and westwards and are called lines of **latitude**; others which run northwards and southwards are known as lines of **longitude**.

Latitude.

To determine latitude we must refer to the **Equator**—a line drawn round the globe midway between the Poles, thus dividing it into the northern and southern **hemispheres**. Now in passing from the Pole to the Equator an observer moves through a quarter of the earth's circumference—*i.e.* 90° of a circle; and while he does so, as was shown on p. 31, the Pole Star sinks 90° from the zenith to the rational horizon. We can draw a circle, running eastward and westward round the globe, at each degree of angular distance between the Poles and the Equator. These circles are all parallel one to another, and are known as lines or parallels of latitude. Their position is measured in degrees northwards or southwards from the Equator. Quito on the Equator is in 0° latitude; London in $51\frac{1}{2}^\circ$ N. latitude; Cape Town in 34° S. latitude; if the Poles could be said to have latitude it would be 90° N. and S. respectively.

The North Pole then is 90° distant from the Equator and the Pole Star is here overhead. If we move 10° southwards from the Pole, our latitude is 80° N. and the Pole Star has sunk 10° from the zenith; if we move 40° towards the Equator our latitude is 50° N.

and the Pole Star has sunk 40° . Thus we get a handy rule for determining latitude by reference to the Pole Star. Observe the number of degrees by which the Pole Star falls short of the zenith ; subtract this number from 90 ; the result gives the latitude of the place where the observation is made. But since the zenith is 90° from the rational horizon, the rule can be put more simply thus : the altitude of the Pole Star at any place on the earth's surface is equal to the latitude of that place.

Longitude.

With the help of latitude alone we are unable to fix definitely the position of a place ; all we can show by means of it is the distance of any given spot from the Equator. Thus, for instance, Pekin, Naples, Madrid, Philadelphia, although far apart are all situated virtually on the circle running round the earth 40° north of the Equator ; in other words, their latitude is roughly 40° N. To make our measurements precise, therefore, we must imagine another set of lines running northwards and southwards from one pole to the other, and cutting the parallels of latitude at right angles. These are called lines of longitude. Since they pass through the poles their centres coincide with the centre of the earth. Circles which have this property are known as **great circles** ; any circle drawn round the earth, the centre of which does *not* coincide with the earth's centre is called a **small circle**. Thus, while all longitude lines are great circles, the Equator is the only parallel of latitude which can thus be described. The rest decrease in size according as their distance from the Equator increases, and at the Poles themselves latitude is reduced to a point ; but all of them—whether 1° or 89° from the Equator—are alike small circles.

The Equator forms a natural starting-point from which to reckon latitude, but with longitude we have no such line fixed by nature. Consequently in different ages, various lines have been taken. For a long while a line passing through the Canary Islands (*Insulæ Fortunatæ*) was adopted as the starting-point, and certain countries have employed a line drawn from Pole to Pole through their capitals. But since the British are the chief seafaring nation of modern times and there is a famous observatory at Greenwich where astronomical and geographical calculations are made, most countries now use a line passing through this place. From this line longitude can be calculated eastwards for 180° and westwards for 180° . The two 180° lines will coincide and can be reckoned either as 180° E. or 180° W. longitude.

Since all these longitude lines run from Pole to Pole and cross the parallels of latitude at right angles, they will divide each of them into 360 parts, each part being 1° of a circle. Now the Equator is a great circle, a circumference of the earth, and it measures roughly 24,900 miles. Hence the value of a degree on the Equator is $\frac{24900}{360}$ —i.e. $69\frac{1}{6}$ miles; this for practical purposes will also be true of a degree of longitude, since circles of longitude, like the Equator, are great circles. But the circles of latitude grow smaller towards the Poles; and since each of them also is divided by the longitude lines into 360 degrees, the length of a degree of latitude varies greatly. Though $69\frac{1}{6}$ miles at the Equator, it measures less than 60 miles at latitude 30° , about $34\frac{1}{2}$ miles at latitude 60° , about 12 miles at latitude 80° , while at latitude 89° it is only $1\frac{1}{6}$ miles. At the poles, of course, latitude is reduced to a point and therefore disappears.

Map Projections.

If we have to represent a large area of the earth's surface in a map we are at once confronted with the difficulty of depicting a curved surface on a flat one. Just as half an india-rubber ball will crumple and tear if it be flattened out, so a map drawn on a globe cannot

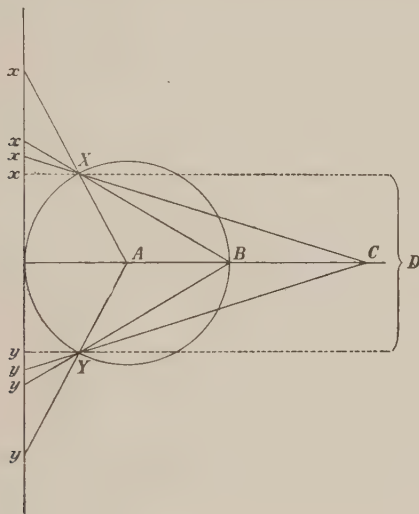


FIG. 19. *Diagram to illustrate map projections.*

The points X and Y on the globe will be represented by x, x, x, x and y, y, y, y on the paper, according to the method of projection employed.

not be transferred to a flat page without distortion or stretching. To obviate this difficulty **map projections** or **map nets** have been devised. Imagine a sphere upon which a map has been drawn but which is transparent. Behind the map surface a light is placed and the shadow of the map is thus projected upon a piece of flat paper. The resulting shadow-map will differ somewhat in shape according to the position in which the light is placed.

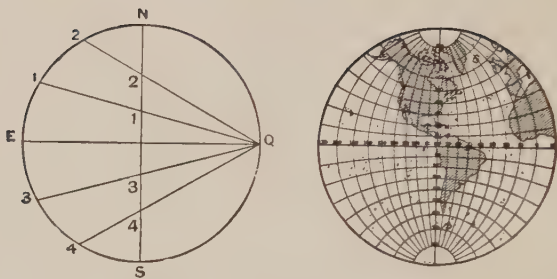


FIG. 20. *Stereographic Projection.*



FIG. 21. *Globular Projection.*

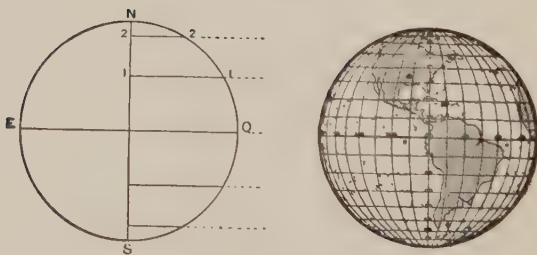


FIG. 22. *Orthographic Projection.*

If the light is at the centre of the sphere (A in Fig. 19) the result is called a **gnomonic** projection. It has the property, useful for navigators, that all great circles upon it appear as straight lines. If the light is moved to B we get a **stereographic** projection. By this method all angles on the globe are represented by equal angles on the map, and thus there is no distortion of outline, although the centre of the map tends to be contracted in size. From C we obtain the much-used **globular** or

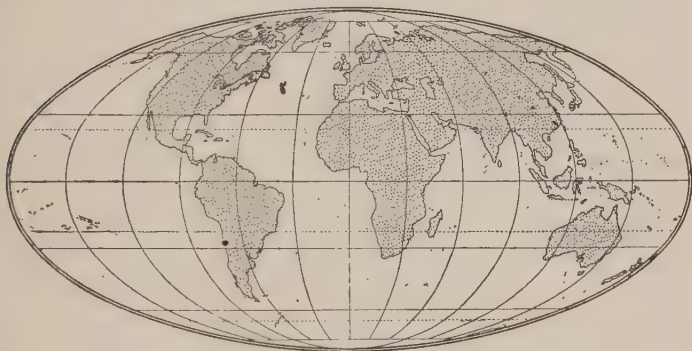


FIG. 23. *Map of the World on Mollweide's Homalographic Projection.*

equidistant projection; while by moving the light to a point so infinitely far away that all the rays of light which fall upon the sphere are parallel, we get the **orthographic** projection, which gives a kind of picture of the earth, but which crowds the parts near the edge of the map so much that it is not very often employed.

There are many other kinds of projections. We may enclose the sphere in a cylinder and project our map upon its inner surface. The well-known **Mercator** map is a good example of this method.* It was invented in the sixteenth century by a Dutchman named Gerhard

* The map on page 11 is on Mercator's projection.

Kremer, whose name was latinized into Gerardus Mercator. His projection has a special value for navigators, because it is the only one which gives the true direction of one point in relation to another ; but we must remember that its scale varies greatly and that it tends to exaggerate areas which are near the Poles. Thus Greenland is shown as of roughly the same size as Africa ; whereas its area is in reality about one-twentieth that of Africa. To avoid this drawback, various equal area maps have been devised, in which all regions are shown in their true relative proportions. **Mollweide's homalographic** projection is a good example of this type of map. But the disadvantage of all of them is that they involve considerable distortion of outline. There are also a number of **conical** projections ; these are based on the assumption that a part of the sphere is enclosed in a paper cone and the map then projected on the inside of it. If the paper is afterwards opened out it will give us a flat map.

The Movements of the Earth.

The earth has two movements ; it spins on its axis and it moves forward through space round the sun. To the former motion we give the name of **rotation** and to the latter **revolution**. We may perhaps compare these two movements with those of a cricket ball which spins owing to the " break " which has been put upon it, and at the same time moves forward from the bowler's hand towards the wicket.

Rotation.

The earth rotates once every 24 hours on an axis which runs from Pole to Pole. Owing to this motion we get the alternation of day and night ; without it one side of the globe would be continually turned towards the sun and so be intensely hot, while the other side

would have an everlasting night of the most excessive cold. For a long time it was thought that day and night were caused by the sun moving round the earth, but it is now known that this motion is apparent only. The sun appears to move from east to west because we on the earth are being carried round from west to east ; similarly objects viewed from a quickly moving train often seem themselves to be moving in the opposite direction to that which the train is taking. Several experiments have been devised to prove that the earth does rotate. One of the simplest was invented by the great scientist, Sir Isaac Newton. If a metal ball be dropped from a great height, instead of falling on the spot immediately beneath the point from which it was let go, it deviates slightly to the east. The reason is that, owing to the earth's rotation, the higher point is moving from W. to E. slightly faster than the lower ; the ball, having the W. to E. velocity of the place from which it was let go, catches up slightly on the velocity of the place upon which it falls.

Since the earth rotates once in 24 hours it follows that any spot on the equator (which is 24,900 miles in circumference) must be carried round at the rate of $\frac{24900}{24}$ —i.e. over 1000—miles per hour. But places situated on the other parallels of latitude, which are small circles, perform a smaller distance in the same time. At latitude 40° the speed is about 800 miles per hour, at latitude 60° about 520 miles per hour, at latitude 80° about 180 miles per hour, while at latitude 89° it is only 18 miles per hour.

It has been said that, owing to the earth's rotation, the sun appears to move through the heavens from E. to W. ; at noon it reaches its highest point in the sky. A shadow cast by a post at noon will point northwards and southwards ; it will thus coincide with a line joining

the two Poles—*i.e.* a line of longitude. All places then which are on the same line of longitude will get their noon at one and the same moment ; and for this reason longitude lines are often called **meridians**—*i.e.* “middyay lines ” (*see* p. 8).

But the earth rotates from W. to E. in 24 hours. This means that any place on its surface will pass through 360° of angular measurement in 24 hours, or 15° in one hour. If therefore it is noon along the meridian of Greenwich (0° longitude), it must be one hour earlier (*i.e.* 11.0 A.M.) along 15° W. longitude and one hour later (*i.e.* 1.0 P.M.) at 15° E. longitude. Thus if it is midday at Greenwich, it is 7.0 A.M. at New York (75° W. longitude) and 7.0 P.M. at Singapore (105° E. longitude). At the Fiji Islands (180° E. or W. longitude) it is midnight. If we travel eastwards (*i.e. with* the earth's motion), we catch up on the earth's rotation ; while by travelling westwards (*i.e. against* the earth's motion), we lose. It may be remembered that Magellan's crew, after circumnavigating the world from east to west, arrived home and found that they had lost a whole day. Phileas Fogg, the hero of Jules Verne's “Round the World in Eighty Days,” did just the reverse. To remedy any confusion that may arise, a **date-line** has been fixed which practically coincides with the 180° meridian. If a ship's captain crosses this line sailing eastwards he omits a day ; for example, if he reaches the date-line at 9.0 A.M. on September 8 he calls it 9.0 A.M. September 9 ; but if he passes it in the opposite direction he reckons 9.0 A.M. September 8 as 9.0 A.M. September 7 and so counts the same day twice over.

Much confusion would also arise if every place used its own local time, by reckoning as noon the moment when the sun crossed its meridian. In actual practice the civilized world has been divided into time-belts. Great Britain, Belgium, France, and Spain all use

Greenwich time—*i.e.*, they reckon as noon the moment when the sun is at its highest on the meridian of Greenwich. Austria, Germany, Norway, Sweden, Denmark, Italy, and Switzerland use **Central European time**, which is one hour in advance of Greenwich time, being calculated from the 15° E. meridian. Western Russia and the Balkan Countries have an **Eastern European time**, which is taken from the 30° E. meridian and is therefore two hours later than Greenwich time. This is also the standard time in Egypt and British South Africa. The United States and Canada have been divided into five time-belts which vary from four to eight hours slower than Greenwich time. The recently introduced "summer-time" consists in putting the clock forward one hour in spring and returning to the proper time in autumn.

From what has been said, it will be possible to see how the longitude of a place can be found. Suppose there are two places, A and B, one of which, A, is situated on a standard time meridian, such as that of Greenwich or 15° E. longitude (Central European time). If we can discover the local time at B when it is noon at A, we can calculate the longitude of B; we must reckon 15° east or west of A's longitude for every hour that B's local time is later or earlier than A's noon. Now B's local time can be kept by setting a clock at twelve at the moment when the sun is at its highest at B; and we can then see what is the time at B when it is noon at A by sending a telegraphic message from A to B, for such a message can be transmitted almost instantaneously. Or we can set a chronometer to the time of A, and then carry it to B and note the difference between the time of A and the local time of B. Suppose, for example, that the clock at B shows 2.0 P.M. when it is noon at A; then B must be 30° east of A; and since A is on a standard time meridian (*e.g.* that of Greenwich or 15° E.) we can easily calculate the longitude of B.

Revolution.

It takes roughly $365\frac{1}{4}$ days for the earth to revolve round the sun. In actual practice we reckon 365 days to the year and add an extra day every fourth or leap year. Even this method is not perfect, for it involves a slight error which increases as time goes on. In 1752 a correction of the calendar, originally suggested in 1582 by Pope Gregory XIII and already adopted by several Continental nations, was introduced into England. It consisted in dropping 11 days and calling September 2,

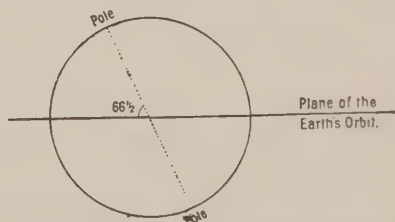


FIG. 24. *Diagram to illustrate the inclination of the Earth's Axis to the Plane of its Orbit.*

The earth *revolves* (i.e. moves forward) round the sun along its orbit, as shown above. But at the same time it is always *rotating* (i.e. spinning) on an axis represented by the dotted line in the figure.

1752, September 14. The reform was opposed by the uneducated mob who feared that their lives were being shortened and who went about crying, "Give us back our eleven days!" The old calendar is still used in Russia; dates there are now thirteen days behind ours. The Russian Christmas Day, for example, falls on our January 7.

The path or **orbit** described by the earth is an ellipse and the sun is situated at one of its foci. This means that at certain times in the year the earth will be nearer to the sun than at other times. When at its nearest, at

the beginning of January, it is said to be in **perihelion** ; when at its furthest, early in July, in **aphelion**.

As the earth revolves, it rotates on an axis which is invariably sloped to the plane of its orbit at an angle of $66\frac{1}{2}^{\circ}$ (see Fig. 24). A school globe is almost always mounted on a stand which gives a slope of this dimension to the axis. But the sun can illuminate only that half

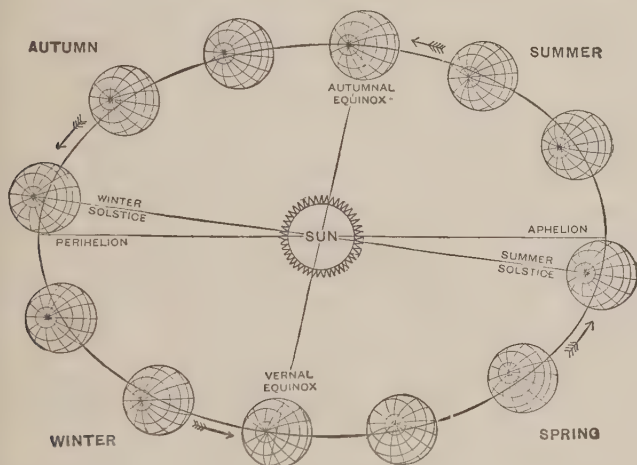


FIG. 25. Diagram to illustrate the Earth's Revolution and the causes of the Seasons.

of the earth which is turned towards it. If the line which separates the light half from the dark half happens to pass through the Poles, every place on the earth's surface will get a day and a night of equal length. Such a state of things occurs twice a year, on March 21 and September 22, and these are called the **Vernal** and **Autumnal equinoxes**. But between March 21 and June 21 the revolution of the earth along its elliptical path causes the North Pole to incline more and more towards the sun ; the boundary between light from dark, therefore, moves

further and further from the Pole, until on June 21 it reaches a position which is traced out by the $66\frac{1}{2}^{\circ}$ N. latitude line—*i.e.* the Arctic Circle. All places within this circle will be unable to escape from the light of the sun; they have continuous day and thus it is possible here to see the “midnight sun.” This condition is known as the **summer solstice**. The opposite state of affairs—the **winter solstice**—occurs on December 21, when the North Pole is turned away from the sun and places within the Antarctic Circle get continuous day.

On the two equinoxes the sun at noon is at the zenith on the Equator; and it is in this same position at noon at the Tropic of Cancer ($23\frac{1}{2}^{\circ}$ N. latitude) on the summer solstice and at the Tropic of Capricorn ($23\frac{1}{2}^{\circ}$ S. latitude) on the winter solstice. After June 21 the condition of sun-at-zenith-at-noon will move gradually southwards and will cross the Equator on September 22, the autumnal equinox. It will reach the Tropic of Capricorn on December 21, where it will appear to turn back, and will recross the Equator on March 21. The word *solstice* literally means a standing-still of the sun, and the word *tropic*, a turning-point; and indeed the sun does seem to stand still at the tropics on the solstices and then to turn back and retrace its path. Notice that the sun never appears at the zenith at noon in any place north of the Tropic of Cancer or south of the Tropic of Capricorn. During the six months Polar day it seems to move round the sky, once every twenty-four hours, describing a spiral path; but at its highest (*i.e.* on the solstices) it reaches an altitude of only $23\frac{1}{2}^{\circ}$ above the horizon.

A reference to Fig. 25—or, better still, to a globe—will also make it clear that to an observer between the Tropic of Cancer and the North Pole the sun at noon (if visible) will always appear due south; and similarly

to an observer between the Tropic of Capricorn and the South Pole, it will always appear at noon due north. Its position in the intermediate zone (the "Tropics") may be summarized as follows, in amplification of what was said on p. 8 :

Autumnal Equinox (September 22) :

Sun-at-zenith-at-noon condition at Equator.

In Northern Hemisphere : Sun-at-noon due south.

In Southern Hemisphere : Sun-at-noon due north.

As sun-at-zenith-at-noon condition moves southwards from Equator to $23\frac{1}{2}^{\circ}$ S. latitude, places in this zone of the Southern Hemisphere will have sun in **north** at noon before it comes to zenith at noon, and in **south** at noon after this condition has passed.

Winter Solstice (December 21) :

Sun-at-zenith-at-noon condition at $23\frac{1}{2}^{\circ}$ S. latitude.

North of $23\frac{1}{2}^{\circ}$ S. latitude : Sun-at-noon due south.

South of $23\frac{1}{2}^{\circ}$ S. latitude : Sun-at-noon due north.

As sun-at-zenith-at-noon condition moves back northwards from $23\frac{1}{2}^{\circ}$ S. latitude to the Equator, places in this zone of the Southern Hemisphere will have sun in **south** at noon before it comes to the zenith at noon, and in **north** at noon after this condition has passed.

Vernal Equinox (March 21) :

Sun-at-zenith-at-noon condition at Equator.

In Northern Hemisphere : Sun-at-noon due south.

In Southern Hemisphere : Sun-at-noon due north.

At sun-at-zenith-at-noon condition moves northwards from Equator to $23\frac{1}{2}^{\circ}$ N. latitude, places in this zone of the Northern Hemisphere will have sun in **south** at noon before it comes to the zenith at noon, and in the **north** at noon after this condition has passed.

Summer Solstice (June 21):

Sun-at-zenith-at-noon condition at $23\frac{1}{2}^{\circ}$ N. latitude.

North of $23\frac{1}{2}^{\circ}$ N. latitude : Sun-at-noon due south.

South of $23\frac{1}{2}^{\circ}$ N. latitude : Sun-at-noon due north.

As sun-at-zenith-at-noon condition moves back southwards from $23\frac{1}{2}^{\circ}$ N. latitude to the Equator, places in this zone of the Northern Hemisphere will have sun in **north** at noon before it comes to the zenith at noon, and in the **south** at noon after this condition has passed.

It has already been said that the earth is in perihelion (*i.e.* nearest the sun) early in January. It might at first sight seem strange that this should be the case in our midwinter, although we must remember that the Southern Hemisphere has its summer at this time of year. The North Pole in our winter is turned away from the sun : as a result, the days in the Northern Hemisphere are short and the sun never rises high in the sky. For instance, in latitude 52° N. at midwinter the sun's rays at noon fall upon the earth making an angle of only $14\frac{1}{2}^{\circ}$ with the horizon ; on midsummer's day at the same time the angle is $61\frac{1}{2}^{\circ}$. Now the more directly the rays of heat fall upon an object, the greater is their heating power. If one holds one's hand in front of the fire far more heat is felt than if the hand were held at the side, so that the heat rays fell upon it obliquely. Again, the sun's rays have to pass through a blanket of air before they reach the earth's surface, and this deprives them of some of their heat. The more oblique are the sun's rays, the thicker is the air-blanket through which they have to pass (*see* Fig. 26), and the greater is the consequent loss of heat. This, then, is an additional reason why places north and south of the Tropics will

get less heat from the sun than the belt which lies between them.

The earth takes in radiant heat from the sun; this form of heat does not warm the intervening space, but it is absorbed by the earth, and then slowly given back or **radiated**. The ocean both takes in and gives out heat more slowly than the land. The layers of air which are in contact with the radiating surface receive heat by **conduction**—*i.e.*, in a similar way to that in which heat travels from the red-hot end of a poker to the handle. During the daytime the earth receives more heat than it loses by radiation and accordingly the temperature of the air on its surface rises; but at night the

reverse will be the case. If, therefore, the night is longer than the day, as is the case in winter, the gain of heat by day will be counterbalanced by the loss of heat at night. Thus although in January the earth is slightly nearer to the sun than in July, this fact is counteracted, so far as the Northern Hemisphere is concerned, (1) by the smaller amount of heat received owing to the obliquity of the sun's rays; (2) by the fact that the gain of heat during the short day is exceeded by the loss of heat during the long night.

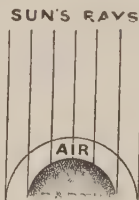


FIG. 26. *Diagram to show the thickness of the air-blanket through which the sun's rays have to pass.*

PROBLEMS AND EXERCISES

1. A society was founded some years ago which sought to teach that the earth was shaped like a tea-cake—*i.e.*, a hemisphere resting on a cylindrical base.

What arguments would you put forward in order to try to convert a member of this society?

2. How far are (a) circumnavigation ; (b) the varying altitude of the pole star, satisfactory proofs of the earth's shape ?

3. Find as accurately as you can by reference to the Pole Star the latitude of the place where you live.

4. Can you suggest a simple method of determining the latitude of a place at noon on the equinoxes ?

5. The shortest distance between two places on the same meridian is along that meridian ; but the shortest distance between two places on the same parallel of latitude is not usually along that parallel. Why ?

(Oxf. Jun. Local, 1911.)

6. By reference to an atlas, find as accurately as possible the latitude and longitude of :

(a) The place where you live ; (b) Paris ; (c) Cape Town ; (d) New York ; (e) Moscow ; (f) Calcutta ; (g) Hawaii ; (h) Wellington (N.Z.) ; (i) Valparaiso ; (j) Pekin ; (k) Cairo ; (l) Winnipeg ; (m) Adelaide.

7. What are the special advantages and disadvantages of a map on an "equal-area" projection ? Mention any purposes for which you would prefer to use such a map.

(Oxf. Sen. Local, 1906.)

8. By reference to the data on pages 34 and 39, construct graphs to show (a) how the length of a degree of latitude varies between the poles and the equator ; (b) how the speed of the earth's surface varies according to the latitude.

9. If it is noon at Greenwich, what will be the time at :

(a) New York ; (b) San Francisco ; (c) New Orleans ; (d) Fiji Islands ; (e) Cairo ; (f) Calcutta ; (g) Shanghai ; (h) Sydney ?

10. The captain of a ship takes observations and finds that at the moment when the sun is due south, the

chronometer shows that it is 2.40 P.M. by Greenwich time. What is his longitude?

11. The longitude of Assuan is 33° E. and of Calcutta 88° E. If an eclipse of the moon begins at Assuan at 10.0 P.M. and is also visible at Calcutta, at what time would you expect it to begin at this latter place?

12. At an observatory in the Northern Hemisphere the sun on December 21 was observed to reach its greatest altitude (16.5°) at 10.0 A.M. Greenwich time. Explain how the latitude and longitude of this place can be determined from these data and make the necessary calculations.

13. Explain carefully why the sun rises only once and sets once in a year at the North and South Poles. Illustrate your answer by a diagram. (Oxf. Jun. Local, 1910.)

14. The greatest altitude which the sun ever attains at London is roughly 62° and the least altitude 15° . Why is this?

15. Calculate the greatest and least altitude which the sun ever attains at:

(a) St. Petersburg (60° N. latitude) and (b) Buenos Ayres (35° S. latitude).

16. How often in the year is the sun vertical over Panama? What is the greatest height above the horizon which it attains at Rockhampton (on the Tropic of Capricorn) and at the North Pole?

(Camb. Jun. Local, 1902.)

17. In what direction would you look for the sun at midday at:

(a) Greenwich on June 21; (b) Melbourne on June 21; (c) Singapore on June 21; (d) Singapore on December 21.

(Camb. Sen. Local, 1900.)

18. "To find the cardinal points, lay your watch flat and turn the small hand towards the sun. Half-way between it and twelve is south." How far is this true?

Does the rule hold good universally? Give your reasons.

19. Explain fully why the sun has greater heating power in the Northern Hemisphere during July than during December. (Oxf. Jun. Local, 1907.)

PART III

CLIMATE

It is important to realize the difference between **climate** and **weather**. By the latter term we mean the atmospheric conditions which prevail in a given place at any given moment. These conditions are constantly changing; the weather in this country, for instance, does not often remain the same for two consecutive days. But climate is *average weather*, and it can be determined only by a series of careful observations extending over a long time. If we visit a district which is new to us we can record the weather from day to day; but long residence there would be necessary before we could accurately describe the climate.

There are many factors which go together to make up climate. Some of them play a larger part in one place than in another; moreover they all tend to act and react one on the other, so that it is sometimes difficult to decide which is the most important. We can, however, say that the climate of any given place is the outcome of the following factors: (*a*) the condition of the atmosphere; (*b*) the amount of rainfall received; (*c*) distance from the sea; (*d*) height above sea-level; (*e*) distance from the equator; (*f*) character of the soil. These co-operating causes of climate must be examined in turn; but, as will be seen, all of them, except perhaps the last, depend more or less directly on the amount of

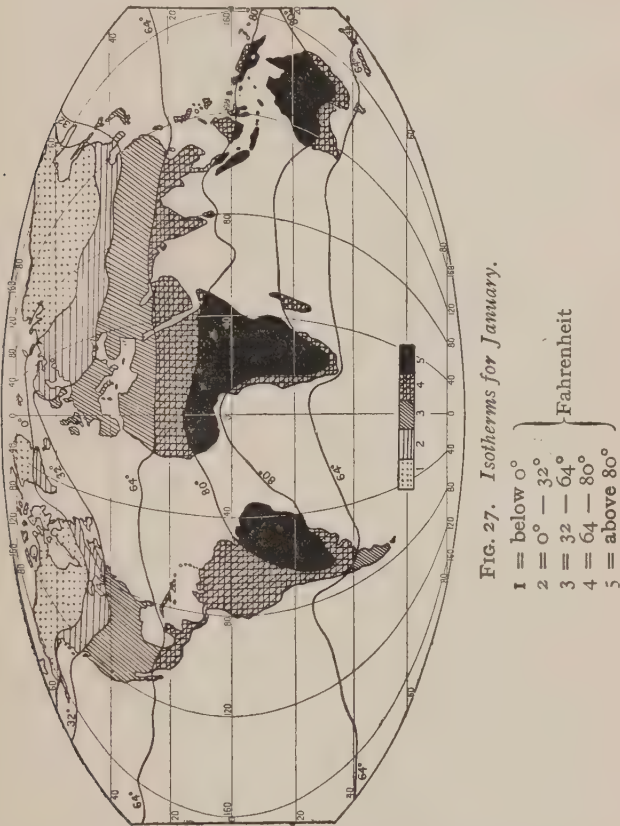
heat which the various parts of the earth's surface receive from the sun.

(a) **Climate as dependent upon the state of the Atmosphere.**

The globe is encased in a covering of air which is probably not more than 100 miles thick and perhaps much less. The density of its lower layers is much greater than that of the upper ones. It consists roughly of one-fifth oxygen and four-fifths nitrogen; but there are traces of other gases, chief of which is carbon dioxide. This is produced by the breathing of animals and the burning or decay of the organisms which are found on the earth's surface; and although a large part of this gas is absorbed by plants, traces of it remain in the atmosphere.

Like any other gas, the air is liable to variations of temperature. We can measure these by means of a **thermometer**, which is a glass tube with a very fine bore, hermetically sealed, and having at one end a bulb. This bulb and part of the stem are filled with mercury or some other liquid. On being heated, the liquid expands and is thus extended in the tube. Similarly the liquid contracts if cooled, and thus its movements in the thermometer tube give an indication of the temperature of the surrounding air. A graduated scale by which these movements can be exactly measured is fixed to the thermometer. The scale most commonly used in this country is that of Fahrenheit, in which the melting-point of ice is fixed at 32° and the boiling-point of water 212° . Scientists, however, usually employ the Centigrade scale, in which these two points are called 0° and 100° . Thermometers have been devised which can record the highest or maximum and the lowest or minimum temperature which is experienced during the day. The difference between these two readings gives the **range of temperature**

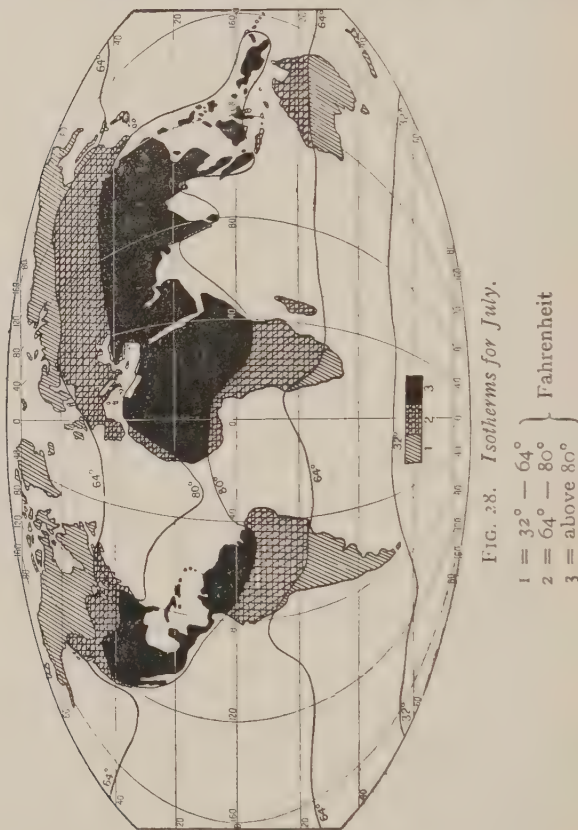
for the day, and their average the **mean temperature**. If observations are taken regularly over a long period of time (as is done at the various meteorological stations



and at some schools), it is possible to determine the mean temperature for a year or for any given month in the year.

If a number of these temperature readings are collected from various places and plotted on a map, we can connect

by lines places which have the same temperature. These lines are known as **isotherms**—*i.e.* lines of equal heat. It is obvious that we can have a map—let us say—of



the British Isles, showing yearly or monthly isotherms, or even isotherms which give the average distribution of temperature throughout a single day or the actual distribution of temperature at any given moment. Figs. 27 and 28 show the mean temperature of the world in

degrees Fahrenheit for the months of January and July.

The atmosphere, like any other form of matter, possesses weight ; although, of course, the weight of a gas is small compared with that of an equal volume of a liquid or a solid. This means that every surface which is exposed to the air is also exposed to pressure owing to the weight of the air. It has been calculated that this weight at sea-level is equal to a pressure of nearly 15 lbs. to the square inch. Since air is a gas the pressure is exerted equally in all directions—upwards, downwards, and sideways alike. Our bodies are naturally adapted to sustain this pressure and therefore it causes us no discomfort ; but if the air be exhausted from any portion of a man's skin, the blood will soon burst through, because the pressure from within is no longer counteracted by the pressure from without. Mountaineers also suffer sometimes from giddiness, sickness, and bleeding owing to the decrease of atmospheric pressure as the covering of air grows less deep and less dense.

Atmospheric pressure can be measured by means of the **barometer**. This instrument consists of a glass tube, well over 30 inches in length, which is closed at one end and open at the other. This is filled with mercury and then inverted in a dish of the same liquid. It will be found that the column of mercury in the tube falls to a height of about 30 inches (A to B). The reason for this is that the pressure of the air on the mercury in the dish is sufficient to support a column of mercury about 30 inches high in the tube, so long as there is a vacuum

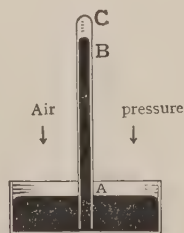


FIG. 29. *The principle of the mercurial barometer.*

(B C) above this column. Another form of barometer is the **aneroid**, in which atmospheric pressure is recorded

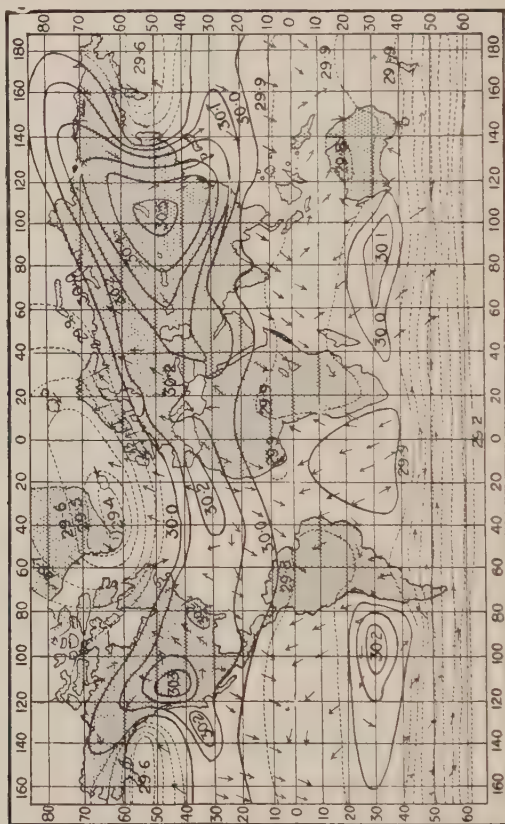


FIG. 30. *Isobars and prevailing winds for January.*
(Barometric pressure in inches of mercury.)

as it acts upon a flat metal box, exhausted of air, and having thin elastic sides.

If air be heated it will expand and lose some of its weight; it is thus caused to rise. When cooled, it contracts, grows heavier, and descends. As a result, in places where the air is rising the pressure due to its

weight is slightly relieved, and the column of mercury in the barometer falls somewhat below 30 inches. On

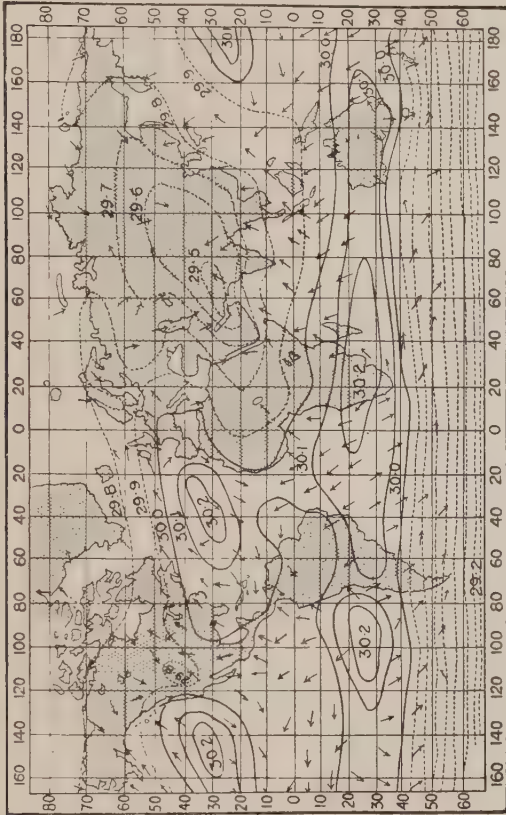


FIG. 31. *Isobars and prevailing winds for July.*
(Barometric pressure in inches of mercury.)

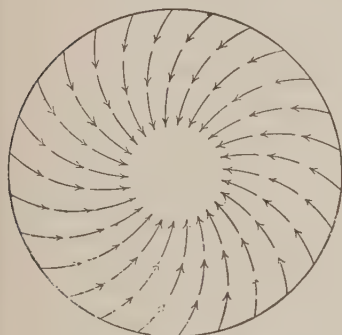
the other hand, if the air is falling its pressure will be slightly increased and the barometer will consequently rise. Areas where the barometric reading is low are therefore said to be areas of **low pressure**, while those where the reverse is the case are areas of **high pressure**. Again, if a barometer be carried up a high mountain its

column of mercury will gradually fall. This is due to the fact, to which reference has already been made, that the air becomes less dense and the atmospheric covering less thick, the higher we rise above sea-level. It has been calculated that the barometer falls 1 inch for every 910 feet of ascent. This instrument therefore is a useful aid in ascertaining the height of a mountain.

It is clear that if a number of barometric readings be taken in a certain place over a considerable length of time, it will be possible to ascertain the average atmospheric pressure there for a given month or for a year. If these pressure data be plotted on a map, it will be possible (as was the case with the temperature readings) to draw lines passing through places which have the same barometric pressure. Such lines are known as **isobars**. Isobar maps of the world for the months of January and July will be found on pages 56 and 57.

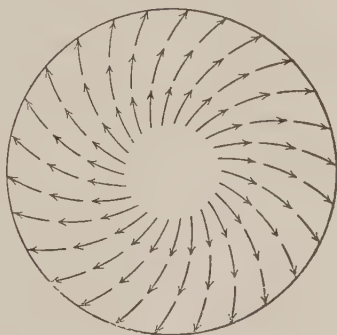
If in a room a window be left open, the cool air from outside will flow in, move towards the fire, and then, becoming heated, will rise up the chimney. These currents are known as **convection** currents. Similarly there is a general tendency for the air which covers the earth to flow from cool regions, where the pressure is high, towards warm regions, where the pressure is low. This fact lies at the bottom of the wind-systems of the world, although other causes may sometimes contribute to modify them. In the Northern Hemisphere air moves downwards and outwards from a high pressure area with a swirl which circles in the same direction as the hands of a clock ; while towards a low pressure area the air is sucked inwards and upwards with a contrary swirl. In the Southern Hemisphere the direction of the swirls is reversed. Air moving outwards from a high pressure area is known as an **anti-cyclone** ; air moving inwards towards a low-pressure area is a **cyclone**.

A good example of these two air movements on a large scale is afforded by the **monsoons**—winds which



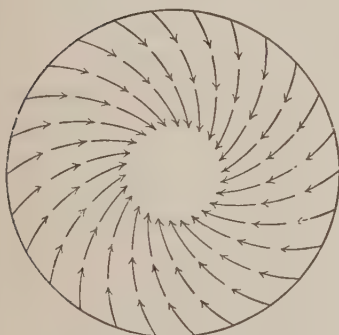
NORTHERN HEMISPHERE : CYCLONE

(Low pressure).



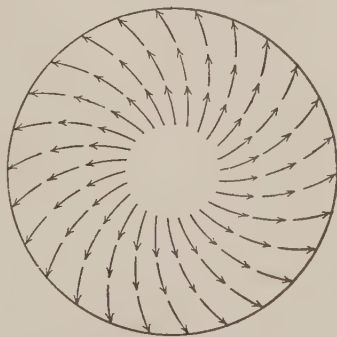
NORTHERN HEMISPHERE : ANTICYCLONE

(High pressure).



SOUTHERN HEMISPHERE : CYCLONE

(Low pressure).



SOUTHERN HEMISPHERE : ANTICYCLONE

(High pressure).

FIG. 32. *Cyclones and Anticyclones.*

blow over southern and eastern Asia and the adjacent oceans. During the winter there is a region in the heart of N.E. Asia where intense cold is experienced. In one place the average January temperature is -53° Fahrenheit—i.e. 85° below freezing-point ! But low temperature

tends to produce high pressure ; and indeed we find that the average January barometric reading for this region is 30.4 inches. As a result the air moves out from this high-pressure area with a clockwise swirl. The winds pass over India chiefly as north-easterlies and over China as northerlies or north-westerlies. But in summer the conditions are reversed. As our July isotherm and

isobar maps show us, there is an area of great heat (average 90°F.) and of low pressure (average 29.4 inches) in north-west India. Towards this the air is sucked in with an anti-clockwise swirl. The result is strong south-westerly winds over southern India and south-easterly or easterly winds over China.

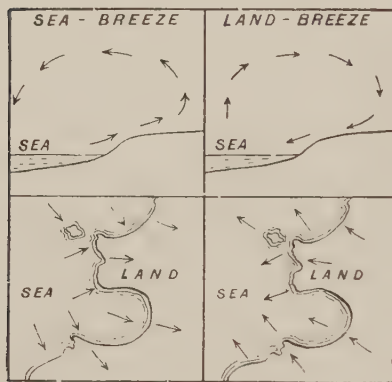


FIG. 33. *Sea-breeze and Land-breeze.*

The upper figures in section ; the lower figures in plan.

This monsoon action can be seen on a small scale at the seaside in warm weather. While the sun is shining, the land takes in more heat than does the sea. Consequently the air over the land is heated and rises during the day and there is an indraught of cooler air from the sea—*i.e.* a sea-breeze. At night the land gives out its heat quickly and becomes cool ; while the sea, which retains heat longer, remains warmer. Conditions are now reversed. The air rises over the sea and a land-breeze is the result.

Apart from local monsoons or cyclonic and anti-cyclonic eddies, we can distinguish a general system of

air-circulation which explains the fact that steady, constant, or prevailing winds are felt in many parts of the world. In equatorial regions the temperature is high and the pressure low; consequently the air moves towards them and the **N.E.** and **S.E. trade-winds** are so formed (see Fig. 34). These steady winds were named

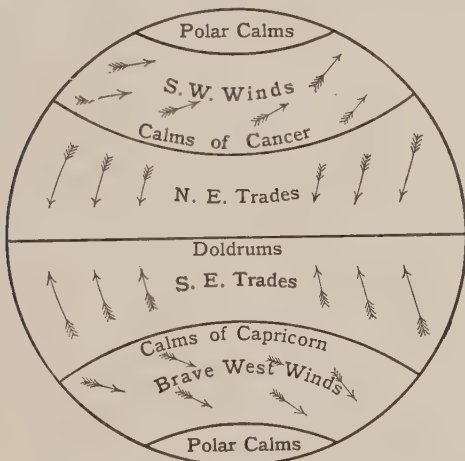


FIG. 34. *General Wind-System of the World.*

N.B. Local variations, due to the interaction of sea and land temperatures, are not shown in this diagram. The heat equator (see p. 64) is also supposed to coincide with the actual equator.

from the fact that they were of great service to merchant vessels in the days of sailing-ships. About 30° N. and S. latitude there are over the oceans belts of calms, where the pressure is high and the air rising. North and south of these are the **prevailing westerlies*** which blow towards the Poles. Now it may be asked: why do not the trade-winds move directly due S. and due N.

* The north-westerlies of the southern hemisphere are sometimes called the "brave west winds." The latitudes in which they blow are known to sailors as the "roaring forties."

towards the Equator? This would be the case if the earth were a stationary globe and if by some means the whole Equator received the maximum amount of heat. But, as was pointed out on p. 39, the earth spins round from west to east, and its velocity varies from over 1000 miles per hour on the Equator to zero at the Poles. Let us now suppose a wind to be starting southwards from the high pressure belt at 30° N. latitude. The speed of the earth's surface here is about 900 miles per hour and the wind at first is carried round from west to east at roughly this same speed. But as it moves from north to south it cannot, owing to friction, pick up the increasing speed of the earth's surface over which it travels. It thus tends to lag a little behind, and instead of blowing straight to the Equator as a north wind it is deflected a little towards the west, and so becomes a north-easterly wind.* To a similar cause is due the deflection of the S.E. trade-wind from the true S. and N. direction.

When the trade-winds reach the Equatorial regions, the high temperature will cause them to rise. We thus get a low-pressure area here which is sometimes known as the **Doldrums**. But the further this air ascends from the earth's surface the less heat will it obtain from the earth's radiation, and it will accordingly be cooled again. This causes an upper or return current which moves back from the equatorial regions towards the Poles. But it starts with (roughly) the west-to-east velocity of the earth's surface at the Equator, and since it is moving over other layers of air, loss of west-to-east speed by friction is much diminished. Also, the further it goes from the Equator, the slower is the velocity of the earth beneath. Consequently, these upper-currents tend to gain on the earth's rotation; instead of blowing

* Notice that winds are named from the points of the compass *from* which they blow.

due S. to N. or N. to S., they become south-westerlies or north-westerlies. Somewhere about the 30th parallel of latitude these return currents or antitrades are sufficiently cool and dense to sink to the earth's surface. Part of their air then returns towards the Equator in the form of trade-winds, but part also continues in its original direction and forms the S.W. and N.W. winds which are found between the Tropics and the Poles. This explanation of the prevailing wind-system of the globe is based on a law which was first put forward by a scientist named Ferrel, and which has been named after him. It says that everything moving on the earth's surface is subject to a deflecting force owing to the rotation of the earth; in the Northern Hemisphere this force deflects to the right and in the Southern Hemisphere to the left. This is, of course, exemplified by the prevailing winds of the globe.

It should be noticed that this general system may be modified owing to the relative temperatures of sea and land which can affect winds locally in the manner described on p. 60. Or a prevailing wind may reinforce a local or seasonal wind; for example, the S.E. trade-wind over the southern Indian Ocean is sucked across the Equator in summer by the strong monsoon indraught into N.W. India, and thus its original direction is slightly changed. Then, again, a prevailing wind may contain cyclonic or anticyclonic eddies, just as a river which is flowing steadily in one direction may none the less contain whirling eddies. The prevailing westerly winds are extremely subject to these eddies, and the weather of the British Isles, for instance, is largely governed by cyclones and anticyclones which are brought by the south-westerlies. Cyclones are associated with rain and unpleasant weather; if the pressure at the centre of the cyclone is very low and the isobars are close together,

gales are experienced. Tornadoes and typhoons are both types of cyclone. In the case of anticyclones, on the other hand, the weather is more settled, being cold but clear and dry in winter, and hot but fine in summer. Anticyclonic conditions, especially if the isobars are far apart, may persist for several weeks, whereas cyclones usually move rapidly and may even follow close one upon the other. Our weather forecasts or meteorological reports, as they are sometimes called, are based largely on telegraphic information as to the weather conditions in places to the west and south-west of us. We can thus gain some indication of the type of weather which the S.W. winds are likely to bring us.

The prevailing wind-system of the globe is ultimately founded on the fact that the sun gives more heat to one belt of the earth's surface than to others. Since the sun is vertically overhead at noon somewhere within the tropics all the year round, this belt of extreme heat will always be found between the two tropics. But this **heat equator**, as it is often called, does not necessarily coincide with the actual Equator; for the sun is at the zenith at noon there only twice in the year—*i.e.* at the equinoxes. In the northern summer (as was explained on p. 44) the sun seems to swing northwards towards the Tropic of Cancer, and therefore the heat Equator will also move in the same direction. It never quite reaches the Tropics itself, because the land tends to lose by night some of the heat which it takes in by day; and thus the heat Equator usually lags a little behind the line of latitude along which the sun is at the zenith at noon. In the same way the heat Equator swings southwards towards the Tropic of Capricorn during our winter months. But these movements of the heat Equator involve a corresponding swing of the whole world's wind-system. In the course of the year it shifts

slightly northwards and southwards, and thus it is possible for some places to have one prevailing wind in summer and another in winter. This shifting of the prevalent winds is illustrated in Fig. 40.

In our summer, when the heat Equator is well to the north of the earth's Equator, the south-east trade-wind is drawn slightly into the Northern Hemisphere; and there, in accordance with Ferrel's Law, it becomes a south-westerly. Over the Indian Ocean this wind continues in the same direction for reasons already explained (*see* pp. 60 and 63), and it forms the south-west monsoon of India. Similarly, when the heat belt is south of the Equator, the north-east trade tends to continue into the Southern Hemisphere as a north-westerly. This wind is drawn into the interior of the great land mass of Australia, where (as the isotherm and isobar maps show) there is an area of low pressure and high temperature. Thus we have repeated over northern Australia in the southern summer a monsoon effect similar to that which is experienced by southern and eastern Asia during the northern summer.

(b) **Climate as dependent upon Rainfall.**

The air always contains a certain amount of invisible water vapour. The actual quantity varies from time to time and from place to place. For example, the British Isles practically all the year round have a very moist air, while in the centre of the big continents, far from the sea, the atmosphere is always very dry. The amount of moisture which air can hold depends upon its temperature. Warm air can hold more of it than cool air. If therefore warm, moisture-laden air is by some means cooled, some of its invisible water-vapour is given up and becomes condensed into a vast number of extremely small drops; and these together become visible in the

form of a **cloud** or **mist**. If the fall in temperature continues, these infinitesimal drops condense still further and the result is a shower of **rain**. The whole process can be illustrated by holding a cold plate over the steam from a kettle; at first the plate becomes covered with a cloud consisting of tiny drops, and these in turn condense still further into larger drops until the surface of the plate is thoroughly wet. If the temperature of the air descends below freezing-point, the water-vapour is frozen into crystals and these fall in the form of **snow**.

It may be asked: What then causes warm moisture-laden air to be cooled and so to give up its water-vapour in the form of rain? One of the chief reasons is that when air ascends and so reaches regions which are far above the earth's radiating surface, its temperature falls. This may either happen in a low-pressure area, where the air is rising spirally; or a wind, which is blowing over the earth's surface, may be deflected upwards by mountain ranges which bar its way. A large amount of evaporation is constantly going on over the sea so long as the sun is shining on it. A warm wind, therefore, in passing over an ocean, will tend to pick up this water-vapour. If now this wind meets with a land-mass which has a mountain barrier facing the ocean it will be forced upward and cooled; and the result will be rain-



FIG. 35. *Effect of Vertical Relief on Rainfall.*

A, A. Rain Shadow.

fall. This fact is well illustrated in the case of India. The S.W. monsoon (*see* p 65), blowing from equatorial

regions across the wide Indian Ocean, brings with it enormous quantities of moisture. When this wind reaches the 3-5-mile high wall of the Himalayas, it rises over it like a wave dashing over a breakwater.



FIG. 36. *Annual Rainfall of the British Isles.*

Consequently the moist air is greatly cooled and the rainfall is proportionately great. A town in Assam called Cherra Punji, which stands on a ridge of hills on the southern side of the Himalayas, is said to receive more rain in the course of the year than any other place in the world. The effect of a mountain barrier in

producing rainfall is also shown on a smaller scale in the case of the British Isles, the highest parts of which are mainly on the west. Against the mountain edge blow the south-westerly winds which are moving from warmer to cooler regions and are bringing with them much moisture which has been picked up from the Atlantic Ocean. It will be seen therefore that the heaviest rainfall (indicated by the thicker shadings in Fig. 36) is on the west of our islands and that the rainfall decreases eastwards. The slope of a mountain barrier opposite to that which receives the rain is known as the **rain-shadow**.

It is obviously important, for purposes of comparison, to be able to measure the amount of rain which falls in any given place and during any given period of time. This is done by means of an instrument called a **rain-gauge**. It consists of an upright metal cylinder, open at the top and containing a funnel which drains into a can below. Any rain which falls over the mouth of the cylinder runs down into the can and is there collected. At fixed intervals the water is emptied out and the amount measured in a graduated glass. This shows in fractions of an inch what would be the depth of the rain which has been collected if it were spread over an area equal to that of the top of the cylinder. The recorded amounts are added up, and in this way the number of inches of rainfall for a month or a year, or the average for any definite time, can be calculated. The average yearly rainfall in London is about 25 inches ; in parts of the Scottish Highlands and of the Lake District it is over 80 inches ; at Cherra Punji (*see* p. 67) it is about 470 inches.

If a number of rainfall measurements be taken in different places and then plotted on a map, lines can be drawn through places which have an equal rainfall, and

these lines are called **isohyets** (*cf.* isotherms and isobars). In Fig. 36 the lines which separate the various types of shading are isohyets. It is often useful to show the amount of rain which falls in any given locality for each separate month of the year. This can be neatly expressed by means of a graph. For example, the average rainfall in inches of Valentia, a small island on the south-west of Ireland, is given as follows: For January, 6.3; February, 5.1; March, 4.1; April, 3.7; May, 3.1; June, 3.6; July, 4.2; August, 4.9; September, 4.4; October, 5.5; November, 5.4; December, 5.6; yearly average, 55.9 inches. This can be shown graphically in the manner illustrated in Fig. 37.

It has been said that, owing to the periodic shifting of the heat Equator, certain belts of the earth have one prevailing wind during part of the year, and another during the rest of it. But since prevailing winds play

a very important part in bringing rain, it is obvious that in some places rainfall may vary enormously according to the season. This fact can be brought out by a careful comparison of the January and July rainfall maps of the world (Figs. 38 and 39). In latitudes higher than 40° the prevailing winds throughout the year are the westerlies; these therefore bring rain at all seasons, especially to the western margins of continents—*i.e.*, the first land which they meet after their journey across the ocean. Mediterranean latitudes (*i.e.* about 40° N. or S.) are influenced by westerlies in winter,

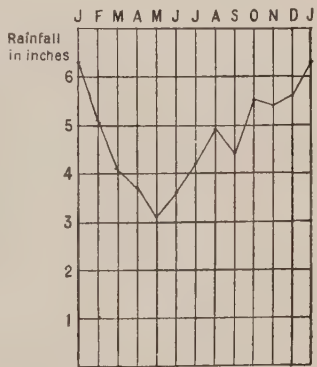


FIG. 37. Rainfall Graph for Valentia.



FIG. 38. Rainfall map of World for January.

but in the summer they come within the tropical high-pressure belt of calms. The result is a wet winter and a dry summer; and this again will be chiefly the case

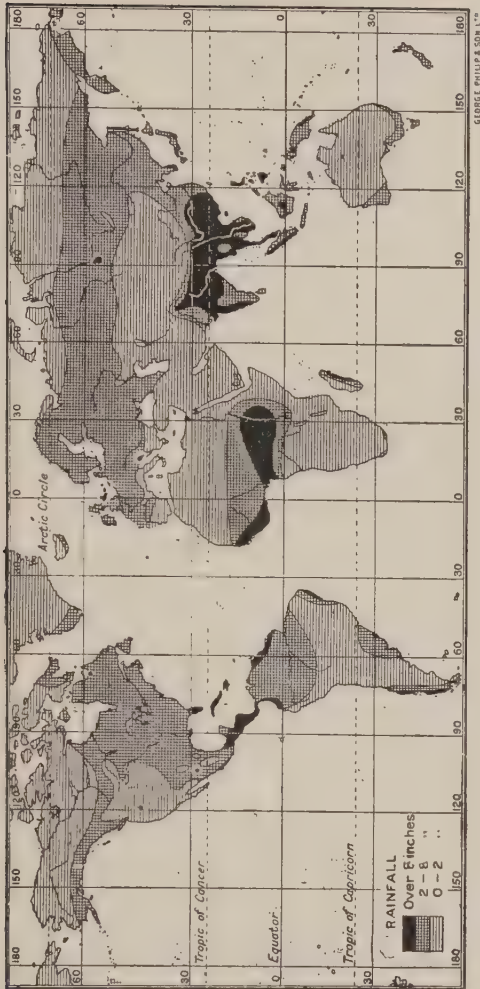


FIG. 39. Rainfall map of World for July.

with western margins. On the Tropics themselves high-pressure calms are constant and rainfall is usually very small. It is in these belts therefore that we shall

find many of the great deserts of the world—*e.g.* the Sahara and the Kalahari in Africa. In equatorial regions rains are almost constant because the air is always warm and moist, and therefore tends to expand, rise, condense its moisture, and produce rain. At the same time, there will be two particularly rainy seasons, one in spring and one in autumn, when the heat Equator crosses the actual Equator. When the heat Equator moves northwards in the northern summer and southwards in the southern summer, it will carry its rain-producing tendency with it; consequently we find heavy summer rains in the two belts which lie between the Equator and the Tropics. Notice that, except on the Equator, the interior of continents is usually dry, because the rain-bearing winds have deposited their moisture before reaching these regions.

The south and east of Asia with the lands adjacent form the chief exception to the general rules laid down above. As was explained on p. 60, these regions are affected in winter by monsoon winds which blow out of a high-pressure area in Central Asia. These winds are cold and dry and are blowing from a colder to a warmer region; they therefore bring little rain. But in summer the direction of the monsoon is reversed. The wind is now sucked inwards from the warm Indian and Pacific Oceans, bearing much moisture, and the consequent rainfall is enormous. Reference has already been made to the terrific rains on the south side of the Himalayas during the south-west monsoon.

The shifting of the world's wind-system and its effect on seasonal rainfall is shown in Fig. 40.

(c) Climate as dependent upon distance from the Sea.

Land both takes in and parts with heat more rapidly than sea does. In summer, therefore, the air over the

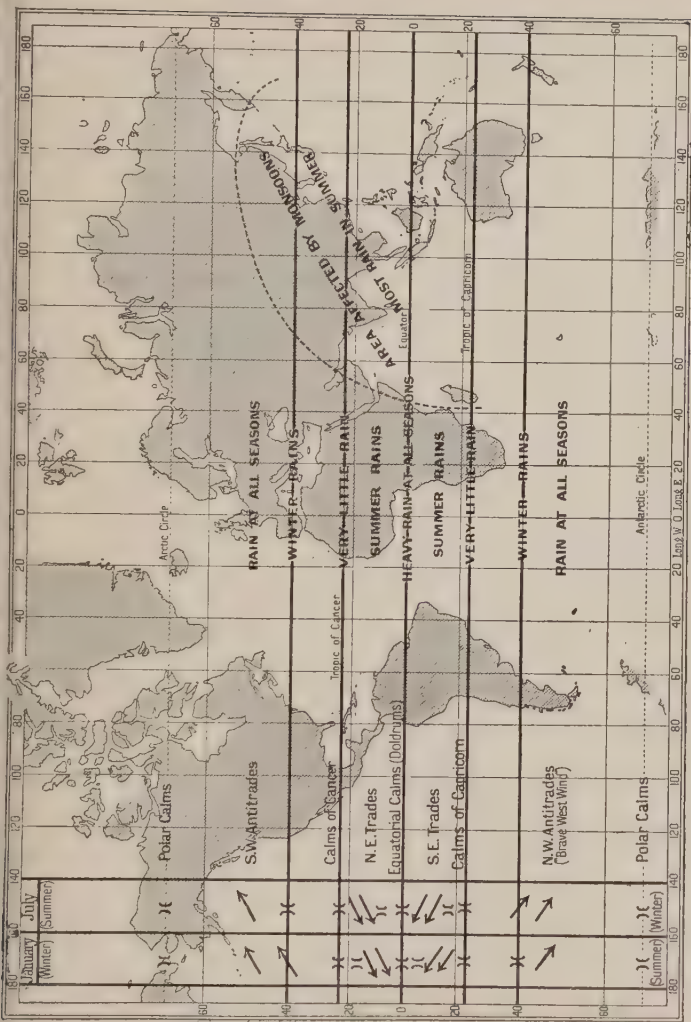


FIG. 40. Map to show how the shifting of the World's Wind-System affects its seasonal Rainfall.

↗ winds.) (calms.

(Notice that in the Southern Hemisphere January is a summer month and July a winter month.)

land tends to be warmer than that over the sea ; but the reverse is the case in winter. A comparison of the July and January isotherm maps of the world (*see* pages 53 and 54) will illustrate this. But since sea parts with its summer heat slowly, it helps to moderate the temperature of the ensuing winter in maritime countries; and similarly, because it takes up heat slowly, it keeps the summer cool in these places. For example, Bristol and Irkutsk are roughly in the same latitude (51° N.) ; but because the position of the former is maritime and of the latter continental, Bristol has an **equable** climate and Irkutsk an **extreme** one, as the following Table will show :

		Average Jan. Temp.	Average July Temp.	Range of Temperature
Bristol	. . .	40° F.	62° F.	22° F.
Irkutsk	. . .	-7° F.	66° F.	73° F.

(d) **Climate as dependent upon Altitude.**

As has already been said, the earth takes up heat from the sun and then radiates it or gives it back into space. It is from this radiated heat chiefly that the layers of air nearest to the earth's surface are warmed. The further therefore the layers of atmosphere are from the surface, the smaller will be the amount of radiated heat which they will receive. For this reason the higher a place is above sea-level, the lower will its average temperature tend to be. It has been estimated that the air grows 1° F. cooler for every 270 feet of altitude. Thus in climbing a high mountain on the Equator, we should pass from regions of high temperature to regions of low temperature and the belts of vegetation would vary accordingly ; at last we might reach a height above which the temperature never exceeds 32° F. and where in consequence snow and ice never melt. The

lower limit of this region is known as the **snow-line**. But the same transitions of temperature and vegetation would be observed if we journeyed on lowlands from the Equator to one of the Poles; though in this case, of course, the changes would be far more gradual. It is said that on the average one must travel from 30 to 60 miles poleward to find a difference of 1° F. in the

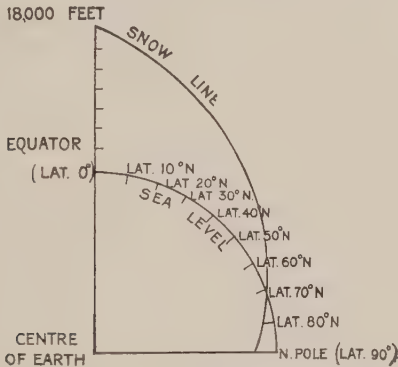


FIG. 41. *Diagram to show the descent of the snow-line from the Equator towards the Pole.*

N.B.—The vertical scale is of course enormously exaggerated as compared with the horizontal scale.

mean annual temperature. We can thus trace a correspondence between the temperature and vegetation belts on an equatorial mountain, and on the lowlands from the Equator to the Poles. The snow-line is at an altitude of about 18,000 feet on the Equator, and it descends to sea-level at about 70° N. or S. latitude. It is naturally higher on the side of a mountain facing the Equator than on the side which faces the Pole.

(e) Climate as dependent on Latitude.

The question may however be asked: Why should the average temperature tend to decrease as we move

further from the Equator and nearer to the Poles? It has already been shown that the sun is at the zenith at noon somewhere within the Tropics all the year round but that it is never vertically overhead at midday anywhere outside this belt. Its greatest altitude decreases from 90° above the horizon in the Tropics to $23\frac{1}{2}^{\circ}$ at the Poles. At London it is 62° . But the amount of heat which a place receives depends partly on the angle at which the sun's rays fall. The larger the angle, the greater the amount of heat. Then, again, the length of the day-time helps to determine the quantity of heat which the various parts of the earth receive. If, as is the case in summer, the day is long and the night short, more heat is taken up by the earth while the sun is shining than is lost during the night-time. Thus the air tends to be warmer when the days are long than when they are short. The Poles certainly get a day of six months duration, but this is counteracted by the oblique angle ($23\frac{1}{2}^{\circ}$ at the most) at which the sun's rays are received, and also by the fact that the six months' day is followed by a night of equal length.

In the Northern Hemisphere the longest day is at the summer solstice (June 21), but it is noticeable that our hottest weather usually comes a month or two later. Similarly, the greatest cold is felt in January, or even February, rather than on December 21. The reason for this is that the land and sea tend to store up the heat which they received when the sun was highest in the sky, and to give it back gradually—the sea more slowly than the land. So also sea and land alike take time to be cooled down in winter, and the coldest months therefore are January over the land and February over the sea.

(f) Climate as dependent on Soil.

Finally, the character of the soil may sometimes help to determine the temperature of the air above it. Dry, sandy soils absorb and radiate heat quickly; and this fact furnishes an explanation of the high day and low night temperatures of such areas as the Sahara. Daily variations of over 90° F. have been observed in such places. On the other hand, moist, clayey soils tend to produce a more equable climate.

PROBLEMS AND EXERCISES

1. Why in the case of Africa is the region of greatest heat (over 80° F.) chiefly north of the Equator in July and south of it in January?

2. From the following data construct graphs:

Average Monthly Temperature in degrees Fahrenheit.

	J	F	M	A	M	J	J	A	S	O	N	D
London . . .	38	40	42	46	55	60	64	63	55	50	42	40
Ben Nevis . .	25	25	23	26	32	38	40	40	36	32	28	25
Moscow . . .	13	13	20	31	46	57	66	63	55	45	34	23
Sydney (N.S.W.)	72	71	70	67	62	56	53	54	57	61	65	68
Tokyo (Japan)	36	38	41	50	57	65	73	77	75	66	55	44

Account, as far as possible, for the variations.

3. What is meant by *mean annual range of temperature*? Mention a district where the range is small and one where it is large. Give the underlying causes in each case.

4. Describe and account for the course of the 32° F. January isotherm across Europe.

5. A rule known as Buys Ballot's Law says: "Stand with your back to the wind and the barometer will be lower on your left hand than on your right." Explain why this should be. Is the rule universally true?

6. If one wishes to compare barometric readings which have been taken in different places, what extra data with regard to these places will be necessary? Give reasons.

7. Describe the positions of the tropical belts of high atmospheric pressure. What are the consequences of their seasonal migrations? What parts of the earth's surface are chiefly affected by their seasonal migrations?

(Oxf. Sen. Local, 1911.)

8. From the following data construct graphs :

Average Monthly Rainfall in Inches.

	J	F	M	A	M	J	J	A	S	O	N	D
London . .	2.4	1.7	1.4	1.9	1.7	2.3	2.4	2.3	2.4	2.6	1.9	2.4
Seathwaite (Cumberland)	13.2	11.2	10.5	6.8	7.4	6.5	9.3	11.7	12.4	12.2	14.1	15.8
Cape Town .	.8	.8	1	1.4	4.1	4.6	3.7	3.5	2.3	1.8	1.2	.9
Para (South America) .	8.2	11.4	12.4	13	8.9	5.4	3.2	3.7	2.3	1.9	2.9	3.8
Hong-Kong .	1	1.3	3.3	5.5	12.7	16.4	16	14.9	12.8	5.4	1.1	1
San Francisco .	4.6	3.4	2.9	1.8	.8	.1	0	0	.2	1.1	2.8	5.2

Account, as far as possible, for the variations.

9. Enumerate the causes which give rise to :

(a) abundant rainfall; (b) great drought. Give examples of districts where these conditions are found.

10. In the trade-wind belt dry regions are found towards the western sides of the land masses, while in higher latitudes they occur towards the east. Explain the reasons for these facts and give examples in illustration of them.

(Oxf. Jun. Local, 1911.)

11. Why has the Iberian Peninsula a lighter rainfall than Switzerland, although the former is further west than the latter?

12. Suppose that the records of daily rainfall have been taken at your school for ten years. How would you calculate :

(a) The average annual rainfall; (b) the average

rainfall for each month of the year ; (c) the maximum and minimum rainfall for each month of the year ?

13. It is found that on the whole the greatest annual rainfall occurs near the Equator, and the amount is less the higher the latitude. How do you account for this ? Mention an important region which forms an exception to this rule, stating how and why it deviates from the rule. (Oxf. Jun. Local, 1909.)

14. Draw an imaginary rainfall map of Africa as it might be if the mountainous side of the Continent were on the *west*.

15. If the Rocky Mountains of North America ran east and west, instead of north and south, what difference would it make to the climate ?

16. Arrange the following places in order according to what you would expect their annual rainfall to be, putting the rainiest first. Give reasons in each case :

(a) San Francisco, Salt Lake City, St. Louis, New York ; (b) Cape Town, Sierra Leone, Walfisch Bay, Zanzibar ; (c) Bombay, Pekin, Singapore, Irkutsk ; (d) Edinburgh, Liverpool, Lincoln, Dover, Margate ; (e) Buenos Ayres, Quito, Santiago, Manaos.

PART IV

GEOLOGICAL GEOGRAPHY

The Origin of the Earth.

IN various parts of the heavens there are vast luminous clouds which are called **nebulæ**. One or two of them are visible to the naked eye (*e.g.* that which is illustrated in Fig. 42), but most can be discovered only with the aid of a telescope. These nebulæ can take various forms. Sometimes they seem to be mere shapeless masses of glowing haze; sometimes they are ring-shaped or spiral; sometimes the nebula has a star at its core. But all nebulæ alike seem to be in motion, and some of them appear to rotate about an axis. The existence of these luminous clouds may give us a clue to the origin of the earth and of the solar system of which it forms part. It has been suggested that as the nebula revolves it tends to cool and condense and contract, and that this contraction causes it to revolve faster. But just as the water cannot remain on a quickly-twirled mop, so the spinning nebula cannot hold together and thus a ring is thrown off round its Equator. This ring will at first spin in the same direction as the nebulous ball, of which it once formed part. But it, too, will lose heat and contract until finally it breaks up and collects into a small sphere revolving round the larger one. In this way the heavenly bodies which make up our solar system may gradually have been evolved out of a nebula.

The larger the mass of any of these bodies, the more slowly will they lose their heat. The sun, for instance, is still in a luminous condition; Jupiter, the largest of the planets, is probably only partially solid and in a red-hot state; while the Moon is a dead world and is



Photo

Dr. Max Wolf

FIG. 42. *The Great Nebula in Andromeda.*

intensely cold. The various stages in the growth of a solar system may be represented by: (1) the formless nebula; (2) the ring-shaped nebula surrounding a nebulous star; (3) the spiral nebula—probably an advanced phase in the formation of rings; (4) the star with its system of planets and their satellites. Of course we cannot assert that this account of the origin of the

universe is indisputably true, for various theories have been put forward which differ in details. But most scientists are agreed that in its main outlines this **Nebular Hypothesis**, as it is called, is the most satisfactory explanation which can be offered.

The nebular hypothesis would at any rate be in harmony with the fact that the central core of the earth is extremely hot. We know that this is so because molten matter is thrown out by volcanoes, and in some places there are springs of boiling water. It has also been found that on an average the temperature in a mine increases 1° F. for every 64 feet of descent. It seems probable then that the interior of our globe consists of an intensely hot material having the consistency of asphalt or white-hot iron. The solid crust is perhaps only 20 to 40 miles thick—that is to say, only $\frac{1}{400}$ to $\frac{1}{200}$ of the total diameter of the earth (7900 miles). None the less, it is this part of the earth's mass which chiefly concerns us in Geography. We are able to gain some information about parts of the earth's crust which once lay buried far beneath our feet, because in the history of our globe immense changes have taken place. As the earth cooled it contracted; and this has caused its crust to be crumpled and cracked and folded, in the same way as the peel of a long-stored apple wrinkles owing to the shrinkage of the substance of the fruit. During this process portions of the crust which originally lay far underground have been forced to the surface; and again other parts have been worn down by rain and rivers and many other forces, until what once lay beneath them has been revealed. The science which describes the earth's crust and the changes which it undergoes is called **Geology**; but it is evident that this science must contribute to form the basis upon which Geography rests.

The Earth's Crust.

The various substances of which the earth's crust is composed are technically known as **rocks** ; this term applies equally to the hardest granite and the softest clay. There are three classes of rocks : (a) **Igneous** ; (b) **Aqueous** ; (c) **Metamorphic**.

(a) *Igneous Rocks.*

These, as their name denotes, have been formed by the action of fire. They were originally in a molten state in the interior of the earth, but have cooled down and solidified. They usually occur in huge shapeless masses and are often crystalline in character. When formed at a considerable depth below the earth's surface and there slowly cooled under great pressure, these rocks are called **plutonic** ; but if ejected and cooled quickly at the surface they are said to be **volcanic**. As an example of the former, we may take granite ; while the latter class includes lava and similar rocks which are formed from matter thrown out by volcanoes.

(b) *Aqueous Rocks.*

Rocks of this class are often formed from the waste of igneous or other rocks, in which case they are called **fragmental**. Enormous quantities of these earlier rocks are gradually worn away by the agency chiefly of rain and rivers. The fragments so formed are carried in suspension by water until they finally settle down and accumulate. Sediment is thus deposited in layers or beds called **strata** ; and under pressure this mud is cemented together and forms a solid mass. Rocks which have been formed in this way are therefore termed **sedimentary** or **stratified**. For example, sand usually consists of finely ground quartz, which is one of the

constituents of granite—an igneous rock. When the tiny grains become cemented together, layers of sandstone are deposited. If the grains are somewhat larger and less smooth, we get “grits,” such as the millstone grit which is found in Derbyshire. In the case of conglomerate, large rounded pebbles, not yet ground down into sand, are found embedded in a mortar of clay or some similar rock. Conglomerate is often called “pudding-stone”—a name which very well describes its appearance. Clay itself is a more finely ground fragmental deposit. It is generally composed largely of tiny particles of felspar, which is another constituent of granite. Under pressure a deposit of clay may become compacted into claystone or mudstone, or again into shale in which form it easily splits up into thin layers. Slate is formed by clay which has been subjected by earth movements to enormous pressure*; it also splits up readily into the thin plates which we use for covering roofs.

In addition to the fragmental class, aqueous rocks include a second group, known as **organic**. These deposits are composed, not of the waste of earlier rocks, but of the skeletons or other remains of tiny plant and animal organisms. Some limestones afford an example of this type of rock. They consist largely of the shells or skeletons of innumerable tiny creatures which once lived in the sea. As they died their remains sank in showers to the bed of the ocean and were there eventually hardened into strata of rock. If a piece of such limestone be examined under a microscope, it will be seen to consist of a large number of tiny shells. Chalk is a softer and finer form of limestone. On the other hand, there are organic rocks which are formed from vegetable organisms. These include the carbonaceous group. Its

* Slate is often classed as a *metamorphic* rock. See p. 90.

chief representative is coal, which consists of decayed vegetable matter long buried under sedimentary deposits and there subjected to pressure and heat and to chemical changes. Flints, again, represent the remains of sponges which formerly grew beneath the sea and the skeletons of which were composed of silica.

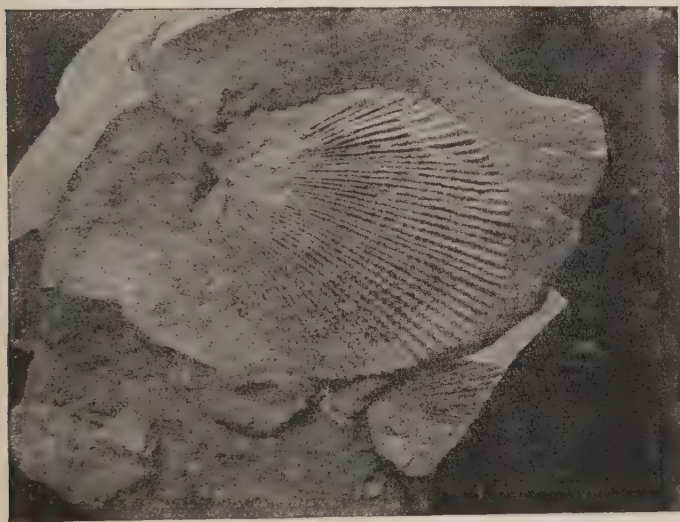


FIG. 43. *A Fossil.*

This is the fossilized shell of a mollusc, and is known to geologists as *Pecten*.

It sometimes happens that remains of plants or animals (e.g. leaves, branches, bones, teeth, shells) become embedded in a sediment as it is being laid down, and they are there kept in a state of partial preservation instead of decaying in the ordinary manner. These remains are known as **fossils**, and they are to be found in many kinds of sedimentary rock. Coal itself is a kind of fossilized material, although it has been much altered by compression and chemical changes.

An indication of how sedimentary rocks were laid down is afforded us by the **oozes** or muds with which the floor of the abysmal ocean is covered and of which specimens have been obtained by deep-sea sounding. In some parts of the ocean bed we find a **red clay**, which is probably composed of volcanic dust which has fallen into the ocean and sunk slowly to the bottom. Elsewhere organic deposits have been discovered; in the so-called **globigerina**, **pteropod**, and **radiolarian** oozes the shells of microscopic sea-creatures predominate, while the **diatomaceous** ooze is composed chiefly of the remains of a minute plant.

The formation of **coral** can in some ways be compared with that of these deep-sea oozes. In the clear warm water of the tropical seas live myriads of tiny creatures which resemble sea anemones in shape, but which have hard calcareous skeletons. These coral **polyps**, as they are called, live on the floor of the ocean, and when they die their hard substance remains. In the course of time these skeletons accumulate and form a rocky platform of coral which grows slowly under the sea. The polyps cannot live out of water and therefore the coral edifice, formed by their remains, cannot rise above the surface. Blocks of coral, however, are often broken off by the action of the waves and so piled up slightly above the level of the sea, in the form of a reef. Coral rocks which fringe a shore are known as **fringing reefs**; but sometimes they lie at some distance from the coast, in which case they are called **barrier reefs**. The best instance of the latter is the Great Barrier Reef, which stretches intermittently for over 1000 miles along the north-east coast of Australia. Between it and the shore there is a channel which averages 20 to 30 miles in width. Often the piled-up coral blocks are partially reduced by the action of the waves to sand, and this binds the whole

mass together. Thus low islands are formed upon which seeds, brought by birds, can take root and grow. Some of these islands are ring-shaped with a shallow lake or



FIG. 44. *The Great Barrier Reef.*

lagoon in the centre. In such cases they are called **atolls**.

The coral-polyp can live only in shallow water (15 to 30 fathoms); but, for all this, it has been found that coral islands are often surrounded by very deep sea.

Various explanations of this puzzle have been suggested. The famous naturalist, Darwin, for instance, put forward the view that the construction of coral began in the form of fringing reefs close to land. In the course of time the land slowly subsided while the coral gradually grew, and thus a barrier reef resulted. Finally the land completely disappeared beneath the sea and then a coral

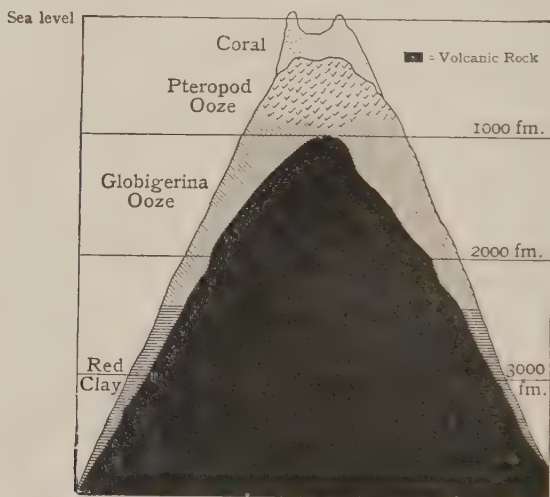


FIG. 45. *Diagram to illustrate Murray's theory of the origin of a Coral Island.*

island would be the final form. The late Sir John Murray has given a quite different explanation. According to him, an elevation from the ocean depth is first caused by volcanic action. On this organic remains, such as the oozes already described, are deposited; and on the top of the submarine mountain so formed the coral rock is built up. It seems probable that this second explanation holds good of the majority of coral formations; but at the same time there are some cases which can best be explained by Darwin's theory.

But even if we can account for the formation of coral islands, it may seem almost incredible that rocks like clay and chalk and sandstone were originally laid down at the bottom of deep seas, in the same manner as the oozes to which reference has been made. Yet such must have been the case ; and these rocks owe their change of position largely to the crumpling and cracking of the earth's crust consequent on its cooling and shrinking. And, indeed, when we remember that the thickness of this solid crust is perhaps only $\frac{1}{400}$ of the total diameter of the earth, we can perhaps imagine how sedimentary rocks, which were laid down on the floor of deep oceans, are now to be found far inland and thousands of feet above sea-level.

Before leaving aqueous rocks, mention must be made of a third group—those which are **chemically formed**. The materials of which they are composed are usually minerals which have been removed from other rocks by chemical action. This class includes rock-salt, some iron ores, and certain kinds of limestone which have been formed in the following way. Water which contains carbon dioxide has the power of dissolving and carrying away large quantities of carbonate of lime. There are in many limestone regions (*e.g.* the Peak district of Derbyshire) huge underground caverns which have been formed by the action of water on limestone. This water is impregnated with carbon dioxide and carbonate of lime ; but on coming into free contact with the air, it loses some of the former and is thus compelled to give up the latter. Consequently, the carbonate of lime is deposited upon anything over which the water flows. This explains the existence of so-called “petrifying” springs, which cover objects placed in them with a coating of carbonate of lime. Similarly, when water, laden with this impurity, finds

its way through the roof of an underground cavern, it tends to deposit a portion of its carbonate of lime, and thus in course of time builds up a pendant of this material, hanging like an icicle from the roof. Such bodies are called **stalactites**. But on the spot where such water drips upon the floor of the cave other masses will be built up, and these are known as **stalagmites**. Often stalactites and stalagmites meet and form fantastic columns. A limestone region is sometimes tunnelled and hollowed by the chemical action of water until it is riddled with caves and underground rivers. There is a district of this kind on the north-east side of the Adriatic Sea. It is called the **Karst**, and geographers have taken this term to denote similar regions, in whatever part of the world they may occur.

(c) *Metamorphic Rocks.*

This name is given to igneous or aqueous rocks which have greatly altered their character owing to heat, pressure, earth-movements, or some other agency. They are usually in a more or less crystalline condition. For example, marble is a crystallized limestone; quartzite, a crystallized sandstone. Gneiss, the most widely distributed metamorphic rock, is a changed form of granite. In some cases the changes have been so great that it is no longer possible to determine the rock's original composition.



FIG. 46. *A Limestone Cave.*
(Cox's Cave, Cheddar.)

A summary classification of rocks :

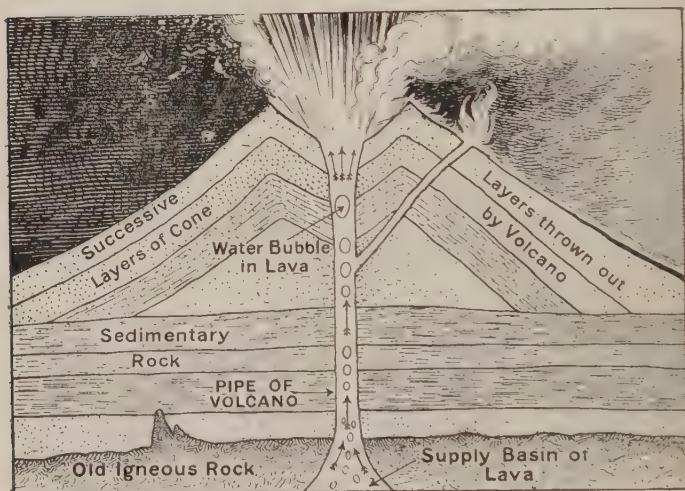
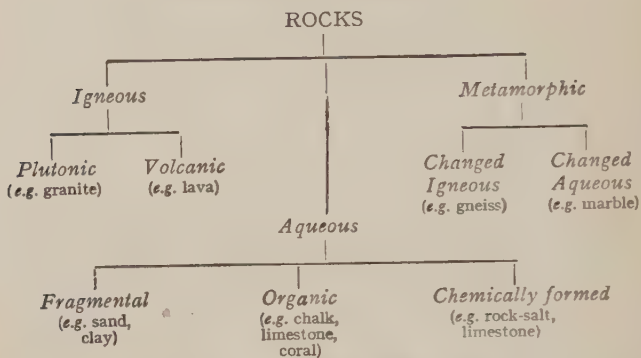


FIG. 47. Diagrammatic Section of a Volcano.

Volcanoes.

During the crumpling and wrinkling of the earth's crust, to which reference has already been made, it may sometimes happen that so deep a rupture or fissure is

made that a means of escape is given to the molten matter of which the interior of the globe is composed. The result is a **volcano**. This may be defined as a conical hill or mountain which has been gradually built up by the accumulation of materials which have been ejected



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FIG. 48. *Columnar Basalt, Giant's Causeway.*

from an opening in the earth's crust. This opening is called the **pipe** or **vent**, and it tends to become choked up when the volcano is not in eruption. At the top of the vent is a cup-shaped orifice known as the **crater**. To the molten matter which wells up through the vent we give the name of **lava**. As this cools, it forms a hard, stony lining ; and when it issues from the crater,

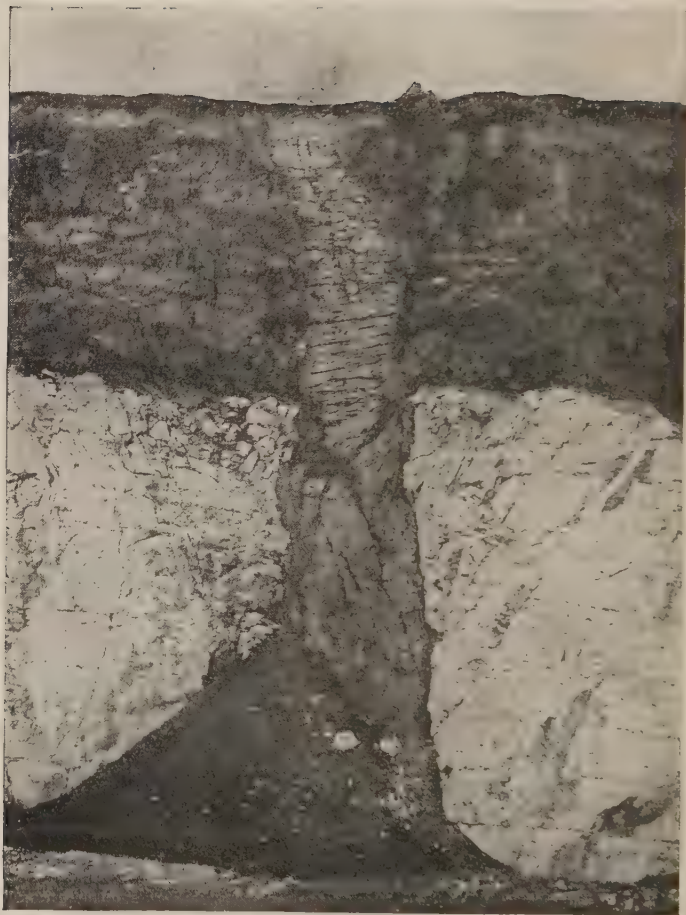


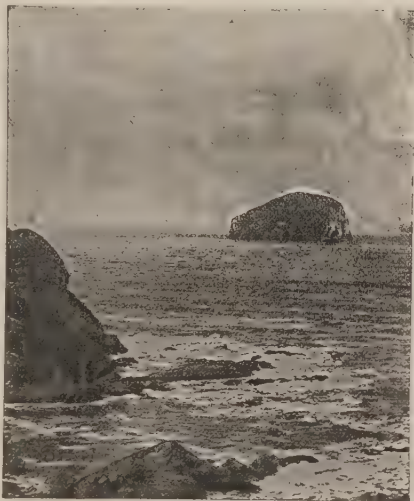
FIG. 49. *Dyke traversing Chalk, Cave Hill, Belfast.*

R. Welch

It sometimes happens that lava is not erupted from a volcanic cone, but wells out in floods through fissures and holes in the earth's crust. When it cools, it forms sheets overlying other rocks which were originally at the surface. These conditions are illustrated in this picture and in Fig. 48. The type of volcanic rock in both cases is a blackish variety known as **basalt**.

it flows down the sides of the volcanic cone in every direction. Sometimes lava in cooling shrinks and splits up into columns, similar to the formation which dried mud sometimes exhibits. This condition is illustrated by the Giant's Causeway in Antrim and Fingal's Cave in Staffa (*see* Fig. 48 and note to Fig. 49).

A volcanic pipe frequently passes through strata of sedimentary rocks (*see* Fig. 47). Thus it may well happen that igneous rocks in their molten form may penetrate aqueous strata and remain there until they cool. Igneous matter which has thus solidified in fissures forms **dykes**; if it penetrates between the layers of aqueous rock, **sills** are formed. Dykes, therefore, are usually vertical and sills horizontal. Or, again the main vent may become stopped up by a plug of hardened lava, and this may cause new minor vents to be opened on the sides of the volcanic cone. In the course of ages, the cone may be worn away, while the hard plug which once filled the ancient crater still exists. Examples of such surviving volcanic plugs are furnished by Bass Rock, in the Firth of Forth, and the hill on which Edinburgh Castle is built.



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FIG. 50. *The Bass Rock, Firth of Forth.*

During an eruption a volcano at first gives out clouds of steam, generated from water which has percolated through the earth and come into contact with the molten lava. This steam expels in fragments the rock which has hitherto choked up the vent ; and when a passage has been cleared in this manner, volcanic ashes (which often consist of fragments of lava impregnated with steam) and molten rock are thrown out. A section of a volcano therefore would show a series of alternate layers of ashes and lava ; for these layers would have been built up round the central vent by successive eruptions. Sometimes volcanic ash is broken up into a fine dust by the sudden expansion of the steam which it contains. This dust may be carried by the winds for hundreds, or even thousands, of miles. In 1883, for example, there was a phenomenal eruption at Krakatoa, a small island in the Malay Archipelago. The dust thrown out at this time was projected far into the atmosphere and so carried to all parts of the world causing the most wonderful sunset effects in many places. The red clay, mentioned on p. 86, is composed chiefly of fine volcanic dust which has fallen on the ocean and sunk to the bottom.

Geysers.

Evidence of the great heat of the earth's interior is given by the presence in many places of hot springs. Even in our own country, at Bath, there are springs of warm water ; but more interesting than these are the **geysers** which throw out boiling water and, like volcanoes, are subject to intermittent eruptions. The high temperature of these springs is due to the heating of the water as it passes through rocks which are subjected to volcanic influences. The Great Geyser in Iceland is said to throw up a column of boiling water to a height



FIG. 51. *A Geyser, North Island, New Zealand.*

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of 100 feet or more. Similar springs are found in New Zealand and in the Yellowstone Park district of the Rocky Mountains. The heated water of a geyser often holds silica in solution, and this mineral is deposited, as can be seen in the picture (Fig. 51) round the sides of the spring. This siliceous incrustation is known as **sinter**, and it has a brilliant half-transparent appearance. The famous Pink and White Terraces of the North Island of New Zealand were formed of sinter.

Earthquakes.

These may be defined as sudden vibrations or movements of portions of the earth's crust. They are usually the outcome of the contraction which the earth is constantly undergoing and which may cause a cracking and dislocation of part of the crust. It is also thought that earthquakes may sometimes be due to the sudden expansion of steam which has been generated underground and so causes upheavals to take place. All parts of the world seem to be more or less liable to earthquake shocks. They are occasionally felt even in the British Isles, but—speaking generally—are most common and most severe in volcanic districts. They are indeed often connected with volcanic activity and frequently accompany eruptions. An instrument, called the **seismometer**, has been devised, by means of which earthquake shocks can be recorded and measured. Immense damage and consequent loss of life may be occasioned by a serious earthquake. In 1908, for example, Messina and Reggio, together with many neighbouring villages, were totally destroyed in this way, and it has been estimated that nearly 80,000 people were killed. Notice that the site of this earthquake is near the volcanic mountains Etna and Stromboli.

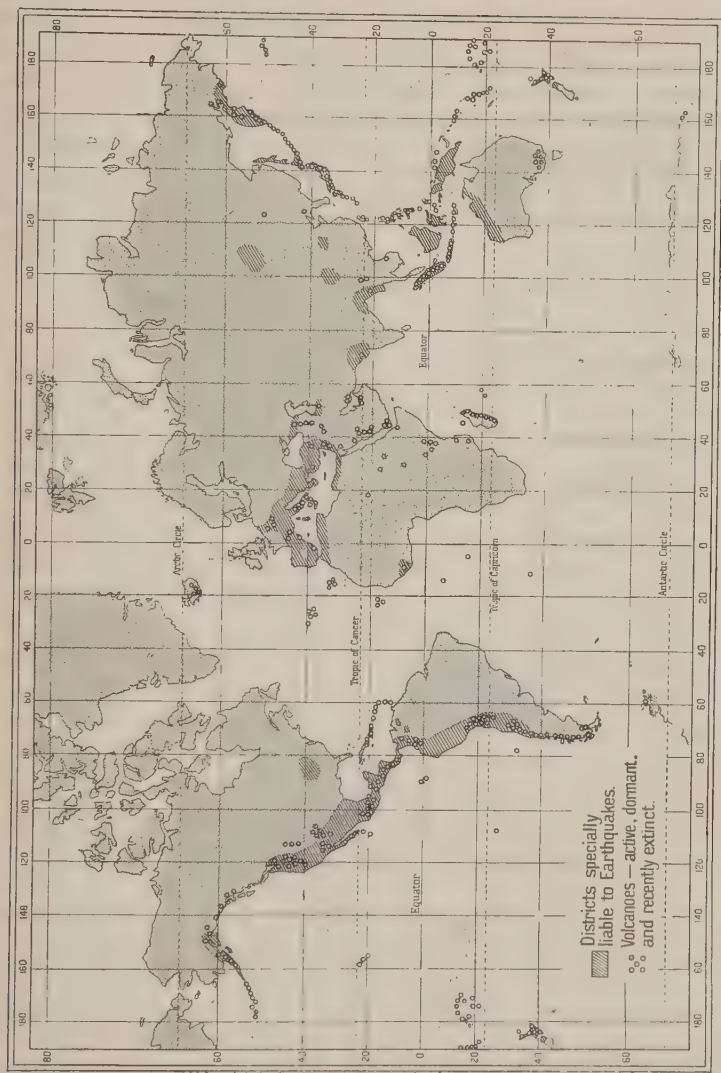


FIG. 52. Map to show the distribution of Earthquakes and Volcanoes.

The Results of Crust Movements.

Stratified rocks, which were originally laid down under water in horizontal layers, are often found tilted or contorted. Upward folds are called **anticlines** and downward folds **synclines**; and we may have a series of these

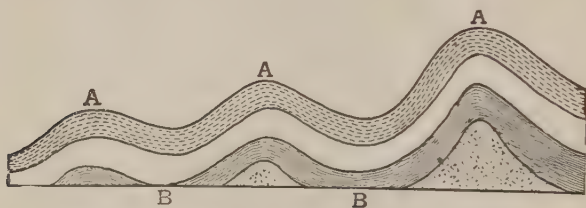
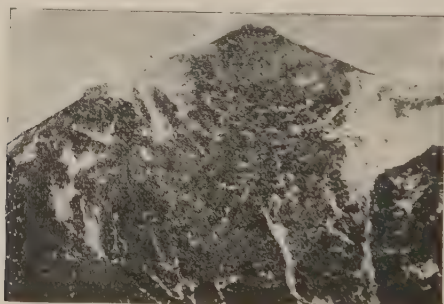


FIG. 53. *Diagrammatic section of "Earthwaves."*

A. Anticlines.

B. Synclines.

"earth waves" running through a long section of the earth's crust. Owing to this folding, the strata in the anticline may be weakened, while those in the syncline are compacted together. Thus it sometimes happens



G. F. Abraham

FIG. 54. *Snowdon Peak from Eastern Ridge.*

The snow resting on the ledges shows the synclinal formation.

that in course of time the anticlines become worn away by the effects of weather, while the harder synclines

remain and form mountains. Snowdon affords a good example of a synclinal mountain. All the lofty mountain ranges of the world, including the Cordilleras of North



H.M. Geological Survey

FIG. 55. *A sharp Anticline planed off by the sea.*
(Near Saundersfoot, Pembroke.)

America, the Andes, and the complicated system which stretches along the north of the Mediterranean and is continued eastwards to the Malay Peninsula, consist of folded mountains (refer to Fig. 88). It may seem strange

that long and lofty ranges such as these should have been formed by the shrinking of the globe and the consequent wrinkling of its crust. We can, however, realize that this is possible when we remember that the earth's diameter

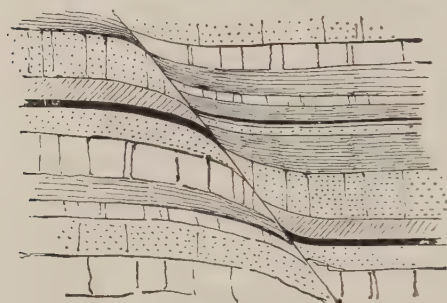


FIG. 56. *Section across a Fault.*

is some 8,000 miles, while its highest mountain (Everest) is only about $5\frac{1}{2}$ miles above sea-level—*i.e.* roughly $\frac{1}{1450}$ of this diameter. If the earth were represented by an apple three inches across, then the height of

Mount Everest above sea-level would be shown by a measurement of not much more than $\frac{1}{5000}$ of an inch, which would be quite imperceptible to the naked eye.

If the rocks, which are being bent by the wrinkling of the earth's crust, are of a rigid character, they will tend to crack rather than to fold and form anticlines and synclines. Cracks of this kind are called **faults**, and when they occur the strata on one side of the fault may slip down. This often



FIG. 57. *Section across a Rift Valley.*
(Central Plain of Scotland).

causes trouble to miners who follow a seam of coal or a vein of ore for some distance, and then find that it suddenly comes to an end. In some cases faults have occurred on a vast scale and large pieces of the earth's crust have slipped down between more or less parallel cracks, thus forming a trough or valley. Depressions

caused in this way are known as **rift valleys**. There is one of great length in East Africa; as the map shows, it runs from the Dead Sea, down the Red Sea, through Abyssinia, and then southwards as far as Lake Nyasa, where it is joined by another rift-valley which contains Lake Tanganyika. Other well-known examples of rift-valleys are the Central Plain of Scotland and the Rhine Valley between Basle and Mainz.

On the other hand, it may happen that a portion of the crust is left standing between faults, while the surrounding country subsides. In this case a plateau or mountain, called a **crustblock**, is

1. Dry floor of the Rift Valley. 2. Lowlands formed of recent deposits. 3. Tablelands composed of sedimentary rocks of various ages. 4. Plateaux of ancient crystalline rocks. 5. Table-lands and mountains of volcanic rock.

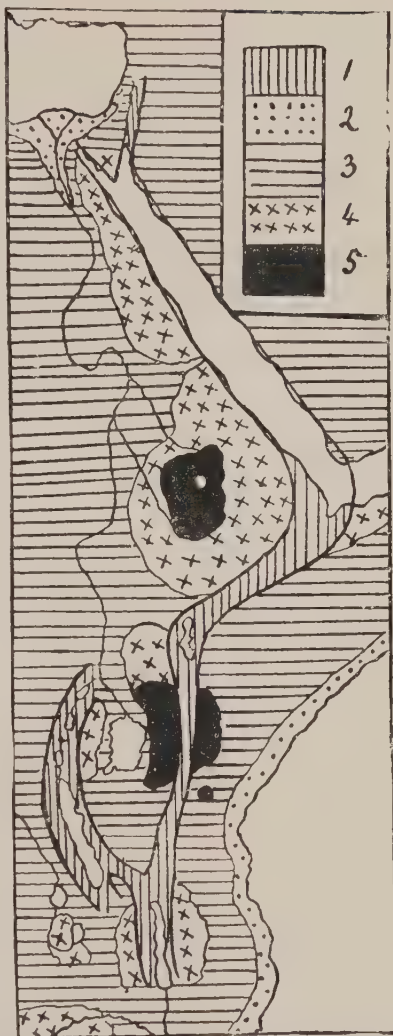


FIG. 58. *East Africa ; Structural Divisions.*

(After J. W. Gregory.)

formed. Examples of this are furnished by the Meseta of Spain and the Island of Sicily.

In summing up, therefore, we may divide the results of the earth's crust-movements into two great groups: (a) the folding and contortion of rocks; (b) the subsidence of areas along the line of faults. The latter are often the accompaniment of earthquakes.

Agents of Denudation.

Hitherto we have dealt with changes in the earth's crust which are due to causes acting from within. But it must be remembered that the surface of the earth is constantly exposed to the action of numerous agents which tend to break up the rocks and carry their debris to fresh places. This whole process is known as **erosion** or **denudation**; while the actual breaking-up of the surface of the land is called **weathering**. The chief agents of denudation are (a) rain; (b) rivers; (c) ice; (d) frost; (e) the sea; (f) wind. Several of these agencies will usually be at work together; and although one of them may predominate in one place, another will be most important elsewhere.

(a) Rain as an Agent of Denudation.

Rain acts upon the earth's crust in two different ways. (1) By virtue of the carbon dioxide which it always contains in a smaller or greater quantity, it acts as an acid upon the rocks with which it comes in contact, and so tends to dissolve some of their constituents. We have already seen (pp. 89-90) how water of this kind eats its way into limestone, dissolving the carbonate of lime and hollowing out the rock into innumerable caves and gullies. It is probable that the beautiful dales of the Derbyshire limestone district were originally caverns, the roofs of which were eaten away and finally fell in,

thus forming a steep-sided valley. The famous Cheddar Gorge in Somerset is also said to have originated thus.

(2) But besides this chemical weathering, rain by beating on the earth's surface tends to loosen parts of it and to wash them away. Moreover the continual soaking and drying of a porous rock helps in course of time to disintegrate it, and the particles thus loosened are carried away by the running water. But this at once leads us on to consider the second chief agent of denudation—rivers.

(b) Rivers as Agents of Denudation.

Rocks may be classed as **permeable** or **impermeable** (or pervious and impervious) according as they allow water to pass through them or not. To the latter class belong clay, granite, etc.; to the former limestone, chalk, and sandstone. A hard rock like granite may, however, become so full of cracks and fissures that water can penetrate through these and collect underground. If a permeable stratum like chalk rests upon a layer of impermeable rock, such as clay, rain will sink through the chalk but will be unable to penetrate the clay. If the strata come to the surface on a hillside, the water



Photochrom Co., Ltd.

FIG. 59. *The Cheddar Gorge, Somerset.*

may percolate underground, above the impermeable clay, until it finally emerges in the form of a **spring**. Simple hillside springs of this kind are very common; other varieties are illustrated in Fig. 60.

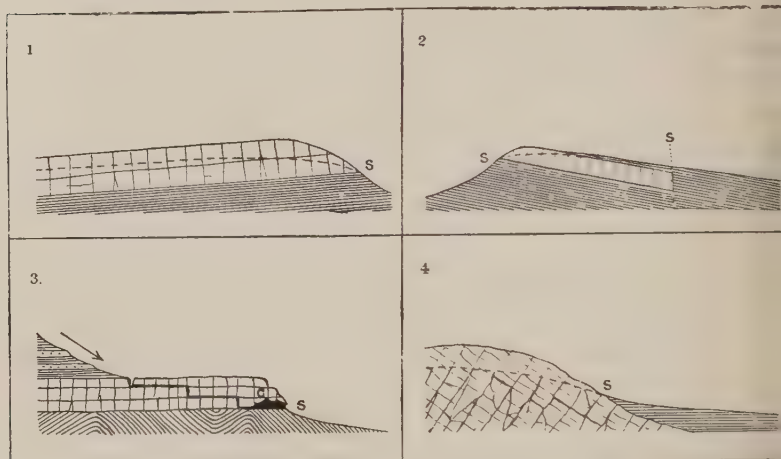


FIG. 60. *Diagrams to show the origin of Springs.*

1. Simple hillside Spring. 2. (left hand) Hillside Spring; (right hand) Spring rising through fault-plane. 3. Spring issuing as a fall-grown stream from a limestone cavern. 4. Spring issuing from granitic rock full of fissures.

Dark shading = impermeable rocks; Light shading = permeable rocks. S, S = Springs.

When a permeable stratum lies between two layers of impermeable rock, but crops out at the surface on either side, as is shown in Fig. 61, the rain will sink in



FIG. 61. *Diagram to show an Artesian Basin.*

a, c, impermeable rocks; b b, permeable rocks. W, W, Artesian Wells.

(This is a section across the London basin.)

at $b\ b$, but will collect underground in the trough of the syncline. If a well (W) be sunk through the impermeable stratum (a), water will be forced by pressure to the surface, if the collecting area ($b\ b$) is higher than the top of the well. A boring of this kind is called an **artesian well**. The fountains in Trafalgar Square are supplied by wells of this sort which are over 300 feet deep. The conditions described above are known as an artesian basin; it is also possible to have an artesian slope, the nature of which will be obvious after a study of Fig. 62. Borings such as those illustrated here are

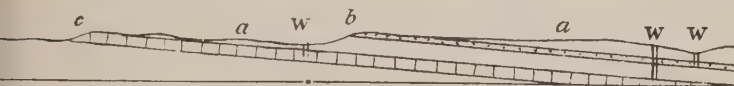


FIG. 62. *Diagram to show an Artesian Slope.*

a, a, a , impermeable rocks; b, c , permeable rocks.
W, W, Artesian Wells.

found in the plain of Central England, as well as in parts of Queensland and South Australia, where the actual rainfall is insufficient. Artesian wells have also been sunk in various parts of the Sahara and have done much to turn barren desert into fruitful land.

Rivers usually originate in springs, though they may also flow out of lakes or be formed (as will be shown at a later stage) by the melting of glaciers. The whole area drained by a river is known as its basin or **catchment basin**—*i.e.* the area which catches the rain which ultimately finds its way to the river. The relatively high land which separates one river-basin from another is known as the **water-parting**.*

* The two expressions "water-parting" and "water-shed" originally had the same meaning. An attempt has been made to distinguish them; but since the term "water-shed" tends to be ambiguous, the beginner will be well advised never to use it, and to confine himself to "water-parting."



Rivers are most effective agents of denudation because they are continually wearing away the surface over which they flow. This is due partly to the friction of the water itself, but far more to the grinding of the waste material or **detritus** against the river bed, over which it is being moved by the current. Much of the finer detritus also is carried in suspension in the form of sediment and is eventually deposited in fresh places. We have already seen how sedimentary rocks were formed out of the waste of igneous rocks, and in this transition rivers doubtless played an important part. In places where there is very little rain, a river may scoop out a very deep and narrow valley, with almost

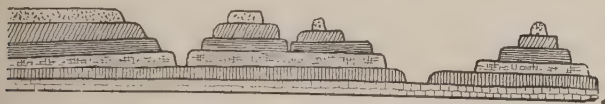


FIG. 64. *Diagram to show Mountains of Erosion.*

perpendicular sides. The river Colorado, in California, flows for part of its course at the bottom of a gorge of this description. Such valleys are called **cañons** or **canyons**. Under ordinary conditions, however, the sides of a river valley are worn away by rain and tributary streams; and in this way shallow trough-shaped valleys are formed. The highlands which are left between such valleys are known as **mountains of erosion** or **residual mountains**. If a hard isolated block is left it forms a **mountain of circumdenudation**. Examples of this are afforded by the **mesas** and **buttes** of western North America, or by Table Mountain in South Africa. The Colorado canyon shows us how great is the power of *vertical* erosion possessed by a river; and if we add to this the additional erosive power of rain and tributaries, we can realize how a comparatively insignificant stream

may, in the course of ages, wear away a wide valley with gently sloping sides.

A tableland which has been deeply trenched by river is called a **dissected plateau**; but eventually the mountains of erosion which lie between the valleys may themselves be worn down and the whole plateau thus reduced to a low-lying plain, known as a **peneplain**. We can thus distinguish a whole **cycle of erosion**, as it is sometimes called. First the level topped plateau is raised by some movement of the earth's crust; then rivers wear out

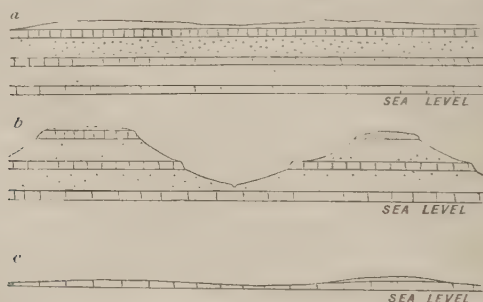


FIG. 65. *The Cycle of Erosion.*

- (a) Uplift of plateau; (b) sculpture of plateau;
(c) reduction of plateau to a peneplain.

valleys which gradually widen until mountains of erosion are left between them; and finally these too are worn down and the whole process is completed.

It is in the upper part of its course that a river has its greatest power of erosion. Here the slope of its bed is most marked and its current is accordingly swiftest. Masses of rock may fall in from either bank, but they are caught by the swirling water and are soon worn away or broken into fragments, one against another. Sometimes a pebble will become lodged in a cavity in the rock over which the river flows. It cannot escape but the current whirls it round and round until at length

it wears out a fair-sized hole, sometimes of considerable depth. Such cavities are known as **pot-holes**, and are often seen in the hard bed of a mountain torrent.



L. Edna Walter

FIG. 66. *Pot-holes.*
(Aar Valley, Switzerland.)

Waterfalls and rapids are most common in the upper part of a river, although they may be found almost anywhere along its course. The various ways in which they may be formed can be gathered from a study of Fig. 67.

Lower down the river erosion tends to be more than counterbalanced by the deposition of sediment which the slower-flowing current lets fall. The river here may curve greatly, for its sluggish stream will be turned aside by every obstacle. Curves of this kind are known as

meanders;* examples are afforded by the lower course of the Seine or the Wye. In the case of a straight river the current flows fastest along the middle of the channel, but in a meandering course it is quickest on the outside of the curves. This means that the bank on this outer side will be worn away more rapidly by the action of the river, while sediment will be deposited on the inner

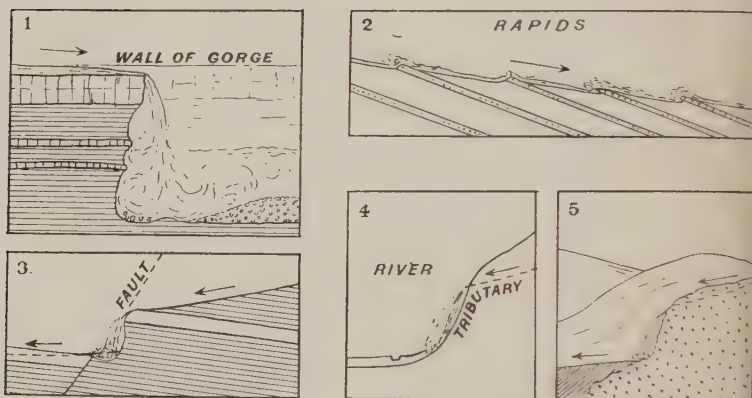


FIG. 67. Diagrams to show the formation of Waterfalls.

1. Hard rocks being undermined by action of water; fall retreating gradually upstream (conditions at Niagara). 2. Rapids; soft rock (white) is worn away more quickly than hard (dotted). 3. Fall due to stream crossing a fault. 4. Fall caused by a river from a side-valley entering main valley at a higher level. N.B.—Side-valleys of this kind are called "hanging valleys" (see p. 130). 5. Fall at junction of hard igneous and soft aqueous rocks.

side of the curve where the current flows more slowly. New soil formed by deposits of river sediment is known as **alluvium**. In course of time a meander may become so large that the river will cut through its neck and so revert to a straight course. Finally the mouths of the

* This noun and the verb "to meander" were taken originally from the name of a winding river in Asia Minor. Compare the derivation of "delta" (p. 116) and "karst" (p. 90).

loop will become silted up and a horseshoe-shaped lake formed at the side of the stream. Abandoned meanders of this kind are known as **cut-off** or **ox-bow** lakes. They can be seen along the lower course of the Towy in South Wales, and are common on the lower Mississippi.

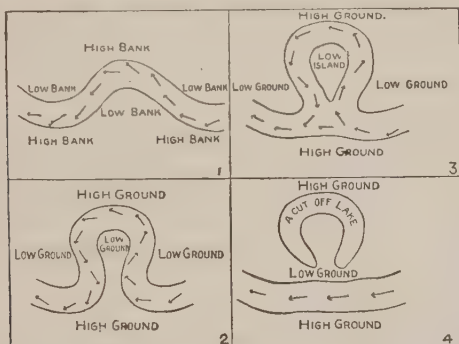


FIG. 68. Diagram to show the formation of a Cut-off Lake.

Notice how a meandering river tends gradually to cut into the high ground on either bank and to deposit

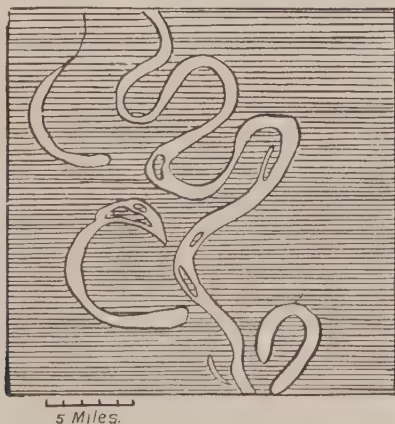


FIG. 69. Meanders of the Lower Mississippi and Cut-off Lakes.
(After W. M. Davis.)

sediment up to flood level on the inside of the curves. In this way a wide and flat valley, known as a **flood-plain**,

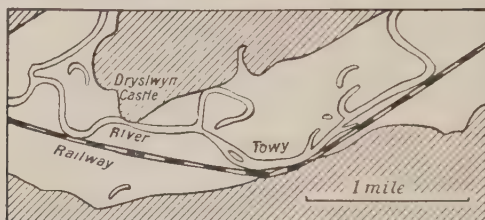


FIG. 70. *Cut-off Lakes and Meanders of the Towy, Carmarthenshire. Alluvium, unshaded.*

may be formed ; and this will normally be found along the middle course of the river—i.e. where it is no longer a mountain stream, but has not yet reached almost the level of the sea. The various stages in the formation of a flood-plain are illustrated in Fig. 71.

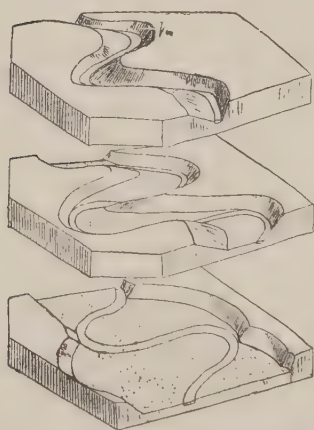


FIG. 71. *Diagram illustrating the formation of a flood plain, by a meandering stream.*
(After W. M. Davis.)

It is near the mouth of a river that the slope of the bed is slightest, the current slowest, and the amount of deposition greatest. In some cases the continual accumulation of sediment has gradually raised the bed of the river and so exposed the adjacent country to the danger of inundation. To guard against this, it has been found necessary to raise the banks of rivers such as the Mississippi and

Hoang-Ho. In the case of the former, these artificially strengthened banks are called **levees**. In spite of

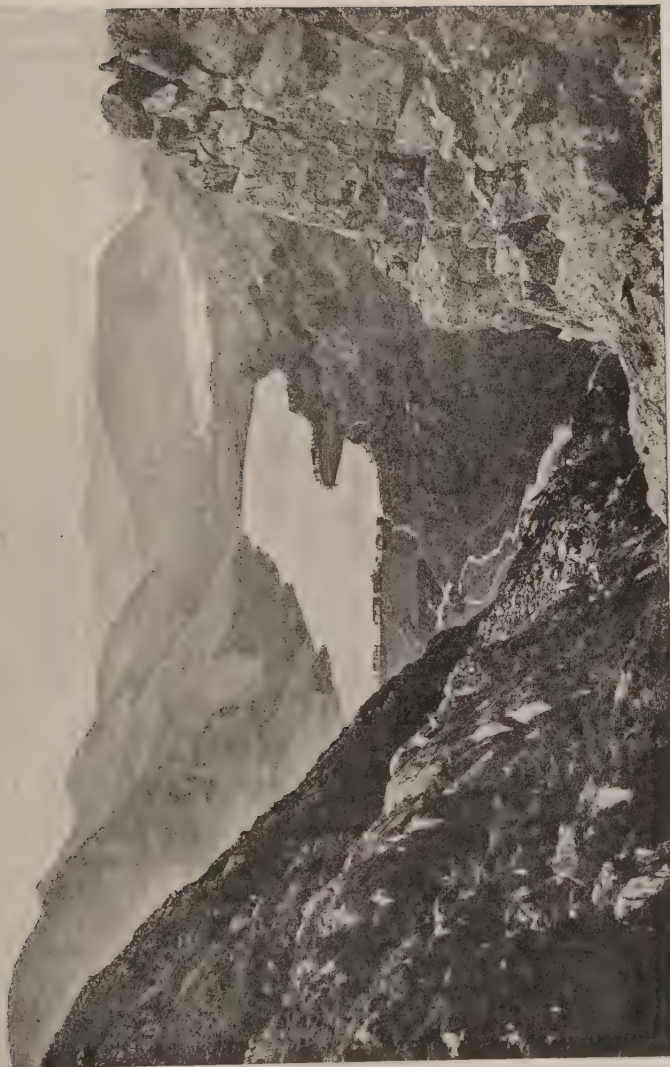
precautions, the Hoang-Ho has frequently altered its course. Previous to 1852, for example, it flowed into the Yellow Sea; but in that year it burst its banks and inundated the surrounding country, causing enormous loss of life. When the flood subsided, it was found that the river flowed along a new channel into the Gulf of Pechili. The new mouth was no fewer than 250 miles from the old one.

Again, when the volume of water in a river is greatly increased by abnormally heavy rains or by a sudden thaw, the stream may rise, overflow its banks, and flood the neighbouring land. But flood water always contains much silt in suspension, and some of this will be deposited to form a thin layer of alluvial mud. In the valley of the Nile there is an annual flood, the average height of which at Cairo is about 24 feet above the normal level of the river. To the rich mud deposited at this time Egypt owes its fertility. The flood is due to the heavy rains brought to the mountains of Abyssinia by the shifting northwards of the heat Equator during our summer (*see* pp. 72 and 73); but the full effect of the flood is not felt in lower Egypt until September or early October.

When a river enters the sea its current is checked and any sediment, which is still held in suspension, is deposited. Where strong tides scour out the mouth of a river, forming an **estuary**, this sediment is prevented from choking up the river mouth, and it accordingly forms **bars** or sandbanks further out. The Mersey, for example, has a bar of this kind, and a channel through it has to be maintained by dredging in order to keep the port of Liverpool open to Atlantic liners. But if the river flows into a comparatively tideless sea (*e.g.* the Mediterranean), the sediment is deposited directly the speed of the current is slackened. In course of time a

fan-shaped plain of silt is built up and the river forces its way across this to the sea through several channels known as **distributaries**. Alluvial land of this kind is called a **delta**. The Greeks originally gave the name to the Nile delta, because on the map it resembles in shape their letter delta (Δ); but we now apply the term to any region of this kind at the mouth of a river. The Mississippi has built up at its mouth curious projections of sediment between which the river flows into the Gulf of Mexico. It has been estimated that this stream carries to the sea some 350 million tons of suspended silt every year. Thus the delta of a big river tends to grow in size, and ports in the neighbourhood may in the course of time be silted up. For example, Aigues Mortes, near the mouth of the Rhone, was once a flourishing seaport; from it Louis IX embarked for his two crusades. But it has been cut off from the Mediterranean by sediment brought down by the river and carried westwards by a current setting along the shore; and now the town stands $3\frac{1}{2}$ miles inland.

If a river flows through a lake, it will deposit much of its silt in the more tranquil waters, and a delta may be formed at the point where it enters. This has occurred, for example, at the eastern end of the lake of Geneva, where the Rhone flows into it. The town of Port Valais which in Roman times stood on the shore, is now nearly two miles inland. It has suffered the same fate as Aigues Mortes. When the Rhone flows out of the lake through the town of Geneva its current is clear, because the sediment which it wore away on its upper course has been deposited in the lake. Just below Geneva, the Rhone is joined by a tributary called the Arve, which flows straight from the Alps, and there is a most noticeable contrast between the turbid water of the mountain



Photo

FIG. 72. *Buttermere and Crummock Water.*

(Refer to map on p. 7. The photo was taken from the crag on the east side of Wanscale Bottom.)

G. P. Abraham

stream and the clear current of the river which has been purified by passing through a lake.

It not infrequently happens that a river, full of sediment, enters a long and narrow lake at right angles near its centre. In this case a delta may be pushed out across the lake and finally may cut it in two. In this manner Sail Beck, in the Lake District, has cut off Crummock Water from Buttermere (*see* Fig. 72 and the map on p. 7); so also in Switzerland the lakes of Thun and Brienz have been separated by the action of two mountain streams.

The bed of a river from source to mouth forms a gentle slope. It is steepest near the source, and it is here that the work of erosion is chiefly being carried on. The



FIG. 73. *Diagram showing successive stages in the lowering of a River's Base Line of Erosion to Base Level.*

curve formed by the river-bed from source to sea is known as the **base line of erosion**. This curve is being worn continually flatter and flatter; but it can never sink quite to sea-level, for then the river would cease to flow. The sea-level line is therefore sometimes called the **base-level**. The course of a comparatively young river may be broken by waterfalls, rapids, or lakes. But in time these inequalities tend to be worn away by erosion or filled up with sediment; thus an old river usually meanders lazily to the sea along a wide valley with gently sloping sides. Sometimes, however, land may be raised by the forces which are at work within the earth's crust. In this case the rivers will be given a new lease of life. Their beds are steepened,

their currents quickened, and their powers of erosion increased. Thus where once the river meandered through an alluvial flood-plain, it has now cut down its channel to a lower level. Here again in the course of ages it may begin to meander again and so to form a new flood-plain. In such cases we often find remnants of the older flood-plain on either side of the valley at a

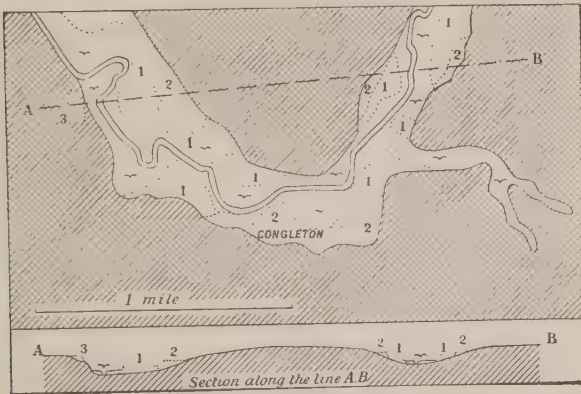


FIG. 74. Terraces of the River Dane, Congleton, Cheshire.
The alluvium is unshaded.

higher level, and these are appropriately known as **terraces**.

By observing and comparing existing rivers, it is possible for us to reconstruct the life-history—if one may use such a term—of a river-system. Suppose a sloping surface along which rocks of different degrees of hardness crop out on the surface at an angle to the slope. When the rain falls on this surface it will collect in streams and flow down; but in so doing it will erode the soft rocks more quickly than the hard. In the course of time falls or rapids may be formed where the streams flow over the hard rock, while flood-plains will

result where the river meanders over the softer surface. The drainage of these flood-plains will now flow at

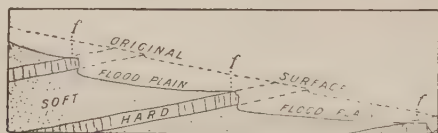


FIG. 75. Diagram to show the effect of hard and soft rocks on the development of a river.

f, f, falls

right angles to the slope of the original surface and will thus produce tributaries to the older rivers. The latter are termed **consequent** rivers, because they took their direction as the natural consequence of the original slope of the ground; but their tributaries are **subsequent** streams, because they were developed subsequently to the original system. These latter by eating away the softer flood-plain rocks, tend to leave the outcrops of hard rock as ranges of hills, running roughly at right angles to the consequent rivers. These hills have one steep slope, known as an **escarpment** or **scarp**, and one gentle slope called a **dip-slope**. The development of scarped hills is illustrated in

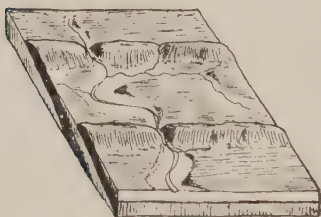


FIG. 76. Diagram to show the development of Escarpments and Dip-Slopes.

A good example of them is afforded by the Chilterns of central England. The valleys in which consequent rivers flow are said to be **transverse**, while those occupied by subsequent rivers are **longitudinal**. These two

terms are sometimes applied to the rivers themselves.

Now suppose two consequent rivers, A and B, each

with its subsequent tributaries. A, being more powerful than B, lowers its valley more quickly, and its tributaries may develop so as in course of time to cut back into the water-parting between A and B. It may thus happen that A's tributary, C, will tap B's tributary, D; and thus the upper waters of B are captured and now form a tributary to A. Meanwhile the gap at E,

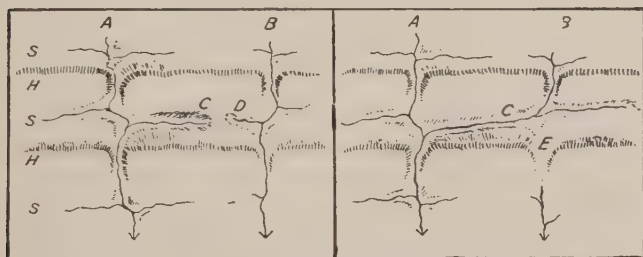


FIG. 77. *Diagram to illustrate River Capture.*

S = soft rocks ; H = hard rocks.

which was once occupied by a river, is now left empty. A breach formed in this manner is called a **wind-gap**; and in the case quoted the river C is said to have **be-headed** B, because it has cut off its head-waters. The whole process is called **river-capture**.

These processes are well illustrated by many rivers in the British Isles. For example, the Chiltern Hills were originally crossed by consequent rivers flowing from N.W. to S.E., but they have been beheaded by the Great Ouse or the Thames, and thus a number of wind-gaps have been left. Advantage of these has been taken by several important railway routes—e.g. the Great Central Railway from High Wycombe to Thame, and the main-line London and North Western Railway at Tring. Similarly the upper Severn probably at one time formed the upper waters of the Thames. But the Avon and

lower Severn, flowing along a band of soft rock parallel to the Cotswolds, have captured its head-waters. Thus, while the Severn from Shrewsbury to Tewkesbury is a consequent river, its lower course is subsequent.

(c) **Ice as an agent of Denudation.**

Running water is certainly chief among the agents of denudation, but next in importance comes ice. The temperature of the air, as we have seen, tends to decrease as one ascends vertically, and eventually snow-line is reached (*see* p. 75). Naturally the covering of snow and ice on a mountain top is continually being increased and the excess is disposed of in three ways: (1) By *evaporation*. It is possible for snow to pass into water-vapour without showing signs of melting, but the process is very slow and the amount of snow on a mountain which disappears in this manner is extremely small. (2) By *avalanches*. Sometimes the accumulation is relieved by large masses of snow and ice which become detached and slide down the mountain side carrying rocks, earth, and trees before them, and sometimes destroying whole villages. Such slides are known as **avalanches**. (3) By *glaciers*.

This third method is the commonest. The upper layers of snow above snow-line compress the lower ones into a substance known as **névé** or **Firn**—half snow and half ice, like a well-squeezed snowball. Moreover, the surface snow is often slightly melted during the day. The water so formed soaks down and during the night freezes together these lower layers. The force of gravity, acting together with pressure from above, causes the whole mass to slide slowly down, and it is squeezed into the valleys below in the form of a **glacier** or “river of ice.”

It may seem strange that a brittle substance like ice



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FIG. 78. *The Gorner Glacier, Zermatt.*

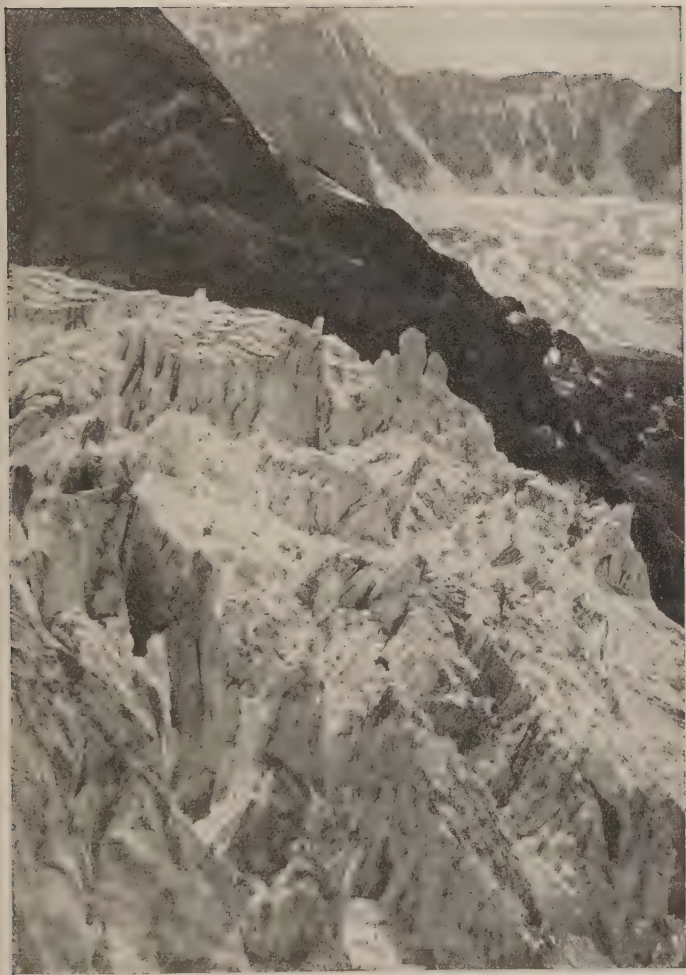
This is formed from several tributaries, as is shown by the medial moraines (see p. 126).

The peak on the extreme left of the picture is the Matterhorn.

can be forced and squeezed in this manner without being broken into innumerable fragments. But ice—like sealing-wax—if subjected to constant pressure for some length of time, has the property of bending without breaking. And again, when ice does break owing to excessive or sudden pressure, the broken surfaces, if they are in contact with one another, have a tendency to freeze together again. This process is called **regelation**. Thus a glacier can be forced down a valley and over a somewhat irregular bed, and yet it will constantly tend to accommodate itself to its course and to heal its own fractures.

However, when a *glacier* has to pass over a steep or very irregular bed, it will crack open, and the broken surfaces, not being in contact with one another, may be unable to freeze together. Thus large fissures may be formed. They are called **crevasses** and may be **transverse**, if they run from one side to the other, or **longitudinal**, if they follow the direction of the glacier itself. Sometimes the glacier bed is so irregular that we find transverse and longitudinal crevasses crossing one another. This gives rise to pinnacles of ice, the sharp edges of which are often melted off by the sun until they form a confused mass of needle-shaped spires covering the whole surface of the glacier. They are known as **séracs**. Crevasses and séracs naturally present dangerous obstacles to mountaineers who have to cross a glacier.

The movement of a glacier, like that of a river, is faster in the centre than at the sides. This can be proved and measured by driving a row of stakes into the ice at right angles to the flow of the glacier. A few days afterwards they will be found to have assumed a curve (B in Fig. 80). Similarly, a transverse crevasse, which was originally straight, often becomes curved. The explanation is that the friction of the ice against



L. Edna Walte'

FIG. 79. *Séracs on the Unter Grindelwald Glacier*

the rocky sides of the glacier tends to retard its movement, while the centre is left more free. This tendency may be illustrated by the case of a river. So also a glacier moves more quickly in a gorge than in a wide and more level valley. The rate

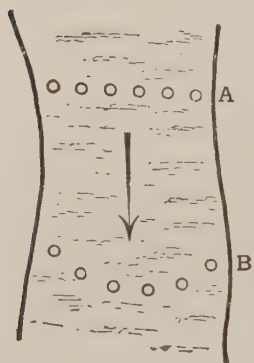


FIG. 80. *Experiment to show the Movement of a Glacier.*

A=Stakes driven into ice.

B=Stakes some days after

of movement accordingly varies greatly. The Mer de Glace, one of the best known Alpine glaciers, is said to advance during summer and autumn from 20 to 27 inches per day at the centre, and from 13 to 19 inches at the side.

As the glacier moves down its valley, rocks which have been split off by the action of frost or by avalanches, may fall upon its surface on either side. This material is continually being accumulated and thus forms two long lines at the edges of the glacier; they are carried forward with the movement of the glacier itself.

These heaps are known as **lateral moraines**. If glaciers from two valleys unite, a central or **medial moraine** is formed; and when a glacier has several tributaries, a number of these medial moraines result (see Fig. 78). Large, flat rocks tend to protect the ice beneath them from the heat of the sun and so to prevent thawing. The rocks thus become poised on pedestals of ice, raised above the surface of the surrounding glacier, and are known as **glacier tables**. But other rocks fall in through crevasses and are dragged along the bed of the glacier, grinding against one another and against the surface of the rock over which they pass. These rocks compose the **ground moraine**. In the bed of a glacier therefore an enormous

amount of detritus is formed, and the stones as well as the glacier bed itself are smoothed and scratched in the process.

At length a point is reached where the supply of ice from above is balanced by loss through melting. Here the glacier ends and a river is formed which rushes out from its lower end or **snout**. The water of this river is



FIG. 81. *View showing the Formation of Icebergs from a Glacier.*

full of sediment which has been produced by the grinding of the ground moraine. Moreover, all round the snout are heaps of moraine material which has been brought down by the glacier and deposited at the point where it ends. These heaps of detritus constitute the **terminal moraine**. In the polar regions it often happens that a glacier or an ice-sheet comes to the sea before it reaches a temperature which is sufficiently high to cause it to melt. In this case the ice breaks off from the lower end of the glacier and floats away in the form of **icebergs**. In the Antarctic Ocean huge tabular icebergs are found;

they consist of enormous masses of ice which have become detached from the edge of the ice-covered South Polar Continent. Icebergs carry with them large quantities of moraine which they drop as they melt ; but in addition to this a terminal moraine or **moraine sill** is often formed under water at the point where the glacier or ice-sheet reaches the sea.

At one time, during a period known as the **Glacial Epoch** or the Ice Age, the northern part of the world was covered by a great ice-sheet which was far larger than that which to-day exists in parts of the Arctic or Antarctic regions. It extended as far south as London



FIG. 82. *Diagram to illustrate Roches Moutonnées.*

The ice has moved in the direction indicated by the arrow. One side of the rock, therefore, has been polished smooth and the other left comparatively untouched.

and New York. Consequently we have many evidences in Britain and elsewhere of the work of glaciers which no longer exist. For example, in the highlands of western Britain we find rounded rocks which have been scratched and smoothed by ice until they look a little like a fleecy sheep ; they have therefore been called **roches moutonnées**. Then again, there are traces of old moraines deposited in places where now there is no longer a glacier. Boulders which have been carried by ice far from their place of origin and deposited upon rocks of a different type are termed **erratic blocks**. Often deposits are found which represent old ground moraines. They usually consist of clay interspersed with stones of all sizes, and are known as **boulder clays**.

It is not very difficult to distinguish valleys which have once been occupied by glaciers. They are long and narrow, while the constant grinding of the ice and the ground moraine has smoothed their sides and so worn them down that valleys of this kind are roughly U-shaped in section. They often contain lakes. These may be formed by the ponding-back of water behind an old terminal moraine, or perhaps by the hollowing out of the floor of the valley where belts of softer rock crossed it, or where for some reason the erosion by ice-action was greatest. Valleys and lakes of this description are very common in the Scottish Highlands,

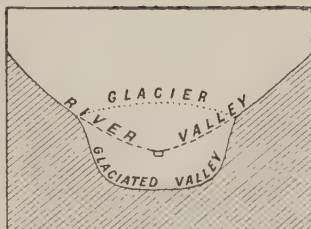


FIG. 83. Section across a V-shaped river valley and a U-shaped glaciated valley.



FIG. 84. A valley system containing a main glacier with tributaries.



FIG. 85. The same valley system after the disappearance of the glacier.

The amphitheatre-like heads of the valleys are called *Cirques*.

Switzerland, Scandinavia, and in fact in any region which has been glaciated. Where the level of the land has sunk, the lower end of a glaciated valley may be flooded by the sea and thus a long, narrow inlet is formed. Examples of this kind are afforded by the **fjords** of Norway and many of the **lochs** on the west coast of Scotland.

A big glacier will wear out a deeper bed than a small one. Let us suppose that a large glacier is joined by several smaller tributaries; then the level of the bed of the former will be lower than that of the beds of the tributaries. If in course of time the glaciers disappear, we shall find a deep valley left, with several smaller valleys running into it at a higher level. Valleys of this kind are called **hanging valleys**, while that which was formerly occupied by the main glacier is termed an **overdeepened valley**. A high pass leading between mountains from one valley to another is known as a **col**.

(d) **Frost as an agent of Denudation.**

If a rock contains crevices (technically known as **joints**) these will soon become filled with rain or snow. But water reaches its maximum density at about 39° F. and then expands once more before it freezes. This process widens the crevice and when the thaw comes pieces of rock are detached. It may be remarked that the bursting of water pipes in cold weather is due to a similar cause. Frost also plays an important part by breaking up the clods of earth during the winter and so helping to prepare the soil for the growing of the seed in spring.

(e) **The Sea as an agent of Denudation.**

It is obvious that every coast is exposed to a large amount of erosion by the sea. The waves constantly

beat upon the land and batter it down by showering pebbles and fragments of rock upon it. Big detached rocks or **stacks** like the Needles, have been broken off



Photochrom Co., Ltd.

FIG. 86. *The Needles, Isle of Wight.*
These are stacks of chalk.

from the mainland in this manner. Again, cliffs are continually being cut away by the erosion which goes on at their bases; and in this way wave cut platforms are formed, while a steep cliff is left. The sea will often wear out a cave at the foot of the cliff. When the tide

is high and the mouth of the cave is blocked with water, the force of the waves from without is so strong that

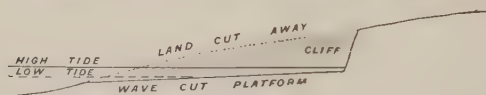


FIG. 87. *Diagram showing Formation of Cliff and Wave-cut Platform.*

the air in the cave is greatly compressed and forced into every crevice of the rock. When the pressure from without is relieved, the air rapidly expands, and in so doing splits the rock and wears away the sides and top of the cave. In course of time a hole, called a **blow-hole**, may be forced upwards through the ceiling of the cave and out on to the top of the cliff. Finally, the cliff may be so worn away that it falls in and so a small cove is formed.

In many ways then coast erosion is constantly going on, and it is accomplished most quickly in places where the cliffs are formed of soft rock. For example, on the coast of Suffolk whole villages have disappeared within the last few centuries. The town of Dunwich, which was once a flourishing port, has been almost entirely destroyed by the encroachments of the sea. So also Ravensburgh, a seaport on the lower Humber at which Bolingbroke landed in 1399, has since disappeared. In other parts the rock materials which have been eroded are being deposited by the sea along the shore. There is thus a certain amount of compensation paid for the constant destruction of some parts of our coast. Spurn Point and Dungeness have been formed by accumulations of sand and shingle. It is said that the latter headland has advanced no less than a mile seawards within living memory.

(f) **Wind as an agent of Denudation.**

On coasts where the wind blows sand from the shore inland, small banks, called **dunes**, may be formed. They are common along the flatter coasts of England and of



L. Eana Walter

FIG. 88. *Sand Dunes near Dungeness.*

Belgium and Holland. In the Landes—a district south of the Gironde—sand has been blown to a considerable distance inland. Attempts have been made to check its advance by planting pine trees.

Sand storms are frequent in deserts, and large quantities of sand are thus carried from one place to another by the wind. The Suez Canal, for instance, has to be continually dredged lest it should be choked up with sand brought from the Egyptian desert. The

sand-blast tends to smooth and to polish the rocks over which it blows; the Great Sphinx affords an interesting example of this type of weathering. Again, the heating of a rock during the day and its cooling by night involve



FIG. 89. *The Great Sphinx, Gizeh.*
The softer layers of the stone are hollowed out by the sand-blasts.

its alternate expansion and contraction; and this process is most marked in a climate like that of the Sahara, where the temperature during the daytime may rise to over 120°F . and fall at night to below freezing-point. In course of time the surface of the rock is loosened and split up, and the whole process is assisted by winds which blow the fragments hither

and thither. It is in fact in this manner that the sandy wastes which form deserts are evolved out of hard rock. Even in regions where there is no sand, the wind may still have some weathering power. Particles of rock, which have been loosened by the action of frost or rain, may be shaken and broken off and carried away by strong winds.

PROBLEMS AND EXERCISES

1. Explain the following lines from Tennyson's *In Memoriam* :

... They say
The solid earth whereon we tread
In tracts of fluent heat began,
And grew to seeming random forms,
The seeming prey of cyclic storms,
Till at the last arose a man.

2. What rocks occur in the district where you live? Obtain, if possible, specimens of them.

3. Can you distinguish any contrasts in scenery between regions with which you are familiar and which have different types of rock?

4. Would you or would you not expect to find fossils in the following rocks: Sandstone; chemically-formed limestone; clay; basalt; marble? Give your reasons in each case.

5. In what ways do volcanoes and geysers resemble one another?

6. What proofs can be advanced to show that some parts of the earth's surface have undergone elevation and that others have subsided?

7. Suppose that some one denied that denudation is going on at the present time. How would you try to prove to him that he was wrong?

8. Briefly describe and account for the formation of the following:

(a) An alluvial soil; (b) an escarpment; (c) an estuary; (d) a valley. (Camb. Jun. Local, 1908.)

9. All lakes constantly tend to become shallower. Explain fully how this happens. Give examples.

(Oxf. Jun. Local, Physiography, 1904.)

10. What happens to the water in lakes which have no outlet to the sea? What are the chief characteristics of such lakes? Give examples.

11. Consult the physical and geological maps of Great

Britain, and then say if you consider the following to be consequent or subsequent rivers :

(a) Forth ; (b) Tweed ; (c) Dee ; (d) Wye ; (e) Great Ouse ; (f) lower Trent. Give your reasons in each case.

12. Explain *longitudinal valley*, *transverse valley*, *col*. Give an example of each.

Why is the arrangement of transverse valleys and cols specially important in determining the positions of roads or railways in a mountainous region ?

(Oxf. Jun. Local, 1909).

13. In what ways do rivers and glaciers resemble one another ?

14. Can you bring forward any evidence from the map or elsewhere to show that parts of North America were glaciated during the Ice Age ?

15. Can you suggest reasons to account for the fact that the west coast of the British Isles is greatly indented, while the east is fairly regular in outline ?

16. Mention, if possible, *three* seaside places which you have visited, and say whether you consider that the sea is encroaching or receding in each case. Give reasons for your answers.

PART V

THE OCEAN

Sea Water.

A LITTLE less than three-quarters of the surface of the globe is covered by sea. Its water has a large amount of mineral matter in solution; it has been estimated that on the average sea-water contains about $3\frac{1}{2}$ parts per 100 of dissolved salts, chief of which is sodium chloride (common salt). The fresh water which is brought down to the sea by rivers also contains mineral matter. Some of this (*e.g.* carbonate of lime, potassium, and silica) is used up by marine animals and plants in order to form their shells or skeletons. But sodium chloride is not so employed, and this is the reason why it is found in sea-water in such large quantities. At the same time sea-water is probably not merely a concentrated essence of river-water, for many scientists think that the oceans were saline when they were originally formed by the first precipitation of rain on the globe. Nevertheless it is probable that, for the reasons already given, the oceans are growing gradually saltier, though this process is extremely slow. The salinity of sea-water tends to vary in different parts of the ocean. Where there is much rainfall or a large amount of fresh water brought by rivers or melting ice, the sea is less salt than where evaporation is great and there is a small supply of fresh water. Thus the

Mediterranean and Red Seas are the saltiest parts of the ocean, while the Baltic Sea is one of the freshest.

Oceanic Circulation.

The surface movements of the ocean are due chiefly to the action of the prevailing winds, although the configuration of land-masses and other causes may tend to deflect a wind-driven current. The correspondence between the movements of the atmosphere and of ocean currents is shown in Fig. 90. In the South Atlantic, for example, the S.E. trade-wind gives rise to the South Equatorial Drift, but is partly deflected by the coast of South America and so helps to form the Brazil Current. In latitudes south of 40° S. there is a West Wind Drift, blown along by the north-westerlies or "Brave West Winds"; and this current keeps to its general direction because there are no great land-masses in its path. The North Equatorial Drift corresponds to the N.E. trade-winds, while the North Atlantic Drift is the oceanic counterpart of the south-westerlies. The circulation of the Pacific coincides in its main outlines with that of the Atlantic. Compare these currents as shown in Fig. 90 with the prevailing winds which are given in Figs. 30, 31 and 34.

Notice that between the North and South Equatorial Drifts there is a Counter Equatorial Current flowing in an opposite direction. The cause of this is that the flow of water from the two Equatorial Drifts raises the level of the sea on the eastern side of continents in equatorial latitudes. The water is, as it were, heaped up on one side of the ocean. This water will naturally try to find its own level; part of it therefore escapes between the two Equatorial Drifts and runs back in a westerly direction. This same cause is at work elsewhere. The water piled up by the N.E. trades in the



Fig. 90. *The World: Structural Divisions of the Land and Ocean Currents.*

The dotted arrows indicate relatively cold currents. The double-headed arrows indicate relatively warm currents, and the single-headed arrows stream-currents.

neighbourhood of the West Indies, escapes as the Gulf Stream; the Kuro Siwo or Japan Current originates in a similar way. So also, in the Southern Hemisphere, the Brazil, Mozambique, and East Australian Currents are all originated by the S.E. trades which heap up water against the eastern side of South America, South Africa, and Australia. Currents which arise in this manner are sometimes called **stream-currents**, while those which are due to prevailing winds are known as **drift-currents**.

The map shows that the general system of oceanic circulation gives rise to several gigantic swirls or eddies. In both the Atlantic and Pacific Oceans there is one of these north of the Equator and another south of it. As might be expected, large masses of floating seaweed and driftwood tend to accumulate in the centre of these eddies. In the north Atlantic one such mass, known as the Sargasso Sea, covers thousands of square miles. Notice that Ferrel's Law (*see* p. 63) holds true of the surface circulation of the ocean as well as of the world's wind-system.

The temperature of the surface layers of the ocean tends to vary according to latitude and to the seasons; but this variation is much less than that of the temperature of the air over dry land. Near the Equator the mean annual surface temperature of the sea is over 80° F., while in the Polar Seas it is somewhere about 28° F. But heat received from the sun can penetrate only a few hundred feet below the surface of the ocean, and in the abysmal depths there is very little variation of temperature. Everywhere a mass of cold water is found which decreases gradually in temperature from about 40° F. at a depth of 500 fathoms to 35° F. or slightly lower at the bottom of the deepest seas. In places where the surface layers of sea-water are blown away by the action of winds, the colder water from beneath wells up to take its place. It is largely for this reason

that in regions where the prevalent winds blow off-shore the currents tend to be relatively cold. Examples of this are furnished by the Peru, Benguela, and West Australian Currents of the Southern Hemisphere, and by the Californian Current of the Northern Pacific.

It should be noted that **waves** differ from currents ; for in the case of the former there is no forward movement of the water. The wave *form* travels on, but the water particles move vertically and return approximately to the points from which they started. This motion may be compared with that of a rope which is shaken at one end, but does not thereby change its place. When, however, a wave approaches a shallow, sloping shore, its lower part is held back, while the crest rushes forward and so forms a breaker. As has been seen, waves are important agents of land sculpture ; but in the open ocean their effect is felt only to a comparatively small depth below the surface.

Tides.

All bodies exert a pulling force one upon another, and this force is known as **gravitation**. The bigger and heavier a body, the stronger is its attraction ; and this power also varies with the distance between the masses which are exerting gravitation. The earth is subject to the attraction more particularly of the sun and the moon, but their pulling force is exerted more easily on the liquid coat of our globe than on its solid part. The greater distance of the sun counteracts to some extent its much greater mass and consequently its attractive power on the waters of the earth is only about two-fifths that of the moon. At the point nearest to the moon, therefore, the waters of the earth are attracted and bulge out ; similarly the solid ocean bed on the opposite side of the earth is drawn away from its covering of

water and a similar bulging occurs here. Midway, between these two places, on either side of the earth, the covering of water will be contracted and low tides will result. But the earth is constantly rotating, and thus the ocean along each line of longitude will feel in turn this pulling power. The tidal wave will thus tend to travel round the whole world in about 24 hours; and because high and low tides occur simultaneously on opposite sides of the globe, each part of the ocean will normally have two of each kind of tide in the 24 hours, with intervals of about 6 hours between them.

As a matter of fact, the interval between high tide one day and the corresponding tide next day is 24 hours 51 minutes. The reason for this is that while the earth is rotating the moon is also revolving round the earth in the same direction and by so doing catches up a little each day on the earth's rotation.

It has already been said that the sun also exercises an attractive power on the waters of the ocean, although that of the moon is the greater. At new moon and full moon the sun and moon are in a line with the earth and they therefore combine their attraction. The high tides under these conditions are higher than usual, and the low tides correspondingly lower. They occur at intervals of a fortnight, and are known as **spring tides**. At the first and last quarter of the moon, lines joining the sun and moon to the earth would form a right angle. In this case the attraction exerted by the one counteracts that of the other, and the tides are therefore much less marked. Under such conditions, which also occur twice in the lunar month, we have **neap tides**.

We must remember that the tides are a vertical movement of the whole body of the ocean, and that this movement is constantly changing its place with the rotation of the earth. Like the undulations of a flag,

the tides are merely wave-forms and not a forward motion of the water itself. Unlike currents or waves, the tidal movement affects the whole mass of the ocean; and it travels at great speed. If the earth were covered with water, the tidal wave would travel regularly round it every day from east to west—*i.e.* in a contrary direction to that of the earth's rotation; but as things are there are many causes which tend to modify both its direction and its height. Variations are caused by the differing depths of the ocean and by the configuration of the great land-masses. In the South Pacific, where these obstacles are least marked, the crest of the tidal wave stretches northwards and southwards, and it moves with fair regularity from east to west. But in the S-shaped Atlantic the crest stretches from the eastern to the western shore of this ocean and in advancing follows its configuration from the south towards the north. In

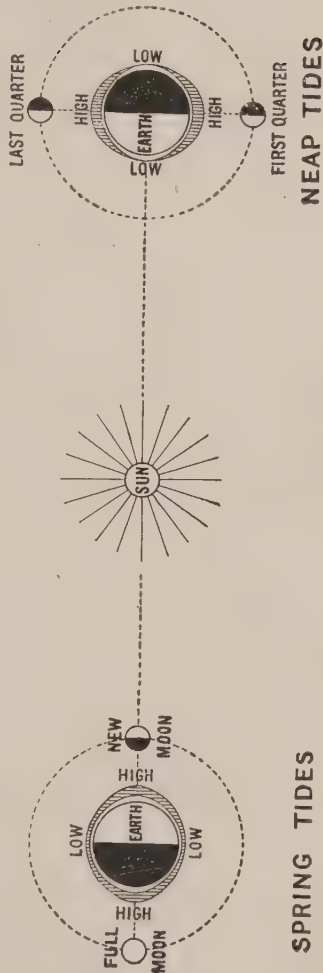


FIG. 91. Diagram to illustrate Spring and Neap Tides.

The moon's tide is denoted by the shading; the sun's tide is left white.

the case of inland seas to which the tidal wave cannot easily penetrate, the tides are very small. On the coasts of the land-locked Mediterranean the variation in height of the water is from 2 to 3 feet ; in the Baltic it is even less. The inland Great Lakes of North America have tides of only a few inches in height.

In the open ocean the height of the tide is probably not more than 2 or 3 feet and is imperceptible, but on a shallow submarine plateau or continental shelf, such as that upon which the British Isles stand, the tidal wave is retarded ; the result is that the purely undulatory movement is converted into a forward movement like that of a current, and the crest of the tidal wave may rise to a considerable height. The difference between average high and low water is called the **range of the tides** ; at New York it is $5\frac{1}{2}$ feet, at Plymouth 12 feet, at London Docks about 19 feet. The "sea-level" or **datum-level**, from which heights on British Ordnance maps are calculated, is 0.65 feet below the average level of the sea at Liverpool—*i.e.* half-way between average high and low water.

As the tidal wave approaches our islands from the south-west it is split up. Part of it passes up the English Channel, part wraps round the north and south sides of Ireland, and part circles into the North Sea round the northern coast of Scotland. The result is that Dover, Liverpool, and Wick have their high tide at about the same moment. Fig. 92 shows the **co-tidal lines** in British waters ; these lines pass through places which have their high water at the time indicated, when noon is the hour of high tide at Liverpool. Sometimes the configuration of a coast may give rise to double tides. For example, the tidal wave which advances up the English Channel is divided into two at the Needles. One part moves up the Solent and brings high water to Southampton ;

meanwhile the other part rounds the Isle of Wight and enters Spithead, and it also causes a high tide at Southampton about two hours later than the Solent tide.

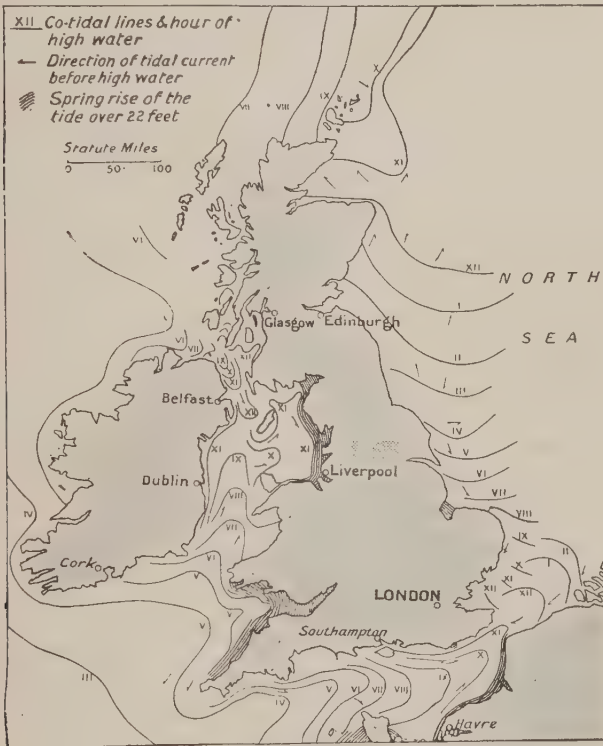
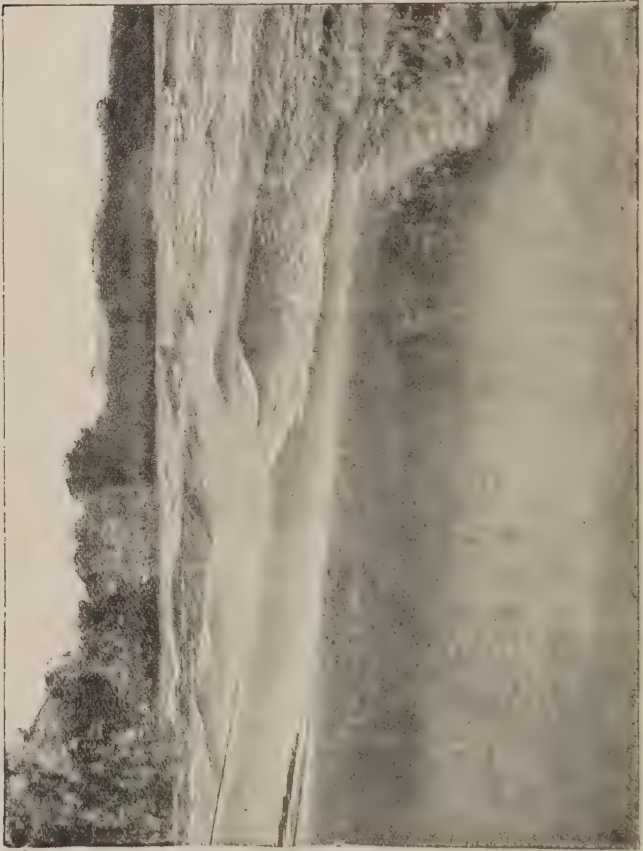


FIG. 92. Map of Co-tidal Lines in British Waters.

Tides make their way in at the mouths of rivers and so form **estuaries**. The point where their influence ceases to be felt is called the **head** of the estuary. When an exceptionally high spring tide is forced into a funnel-shaped estuary, the water may form a huge wave or **bore** which rushes up the river. The Severn bore under

certain conditions forms a wave of 8 or 9 feet in height, while the difference between high and low tide is as



L. M. Burton

FIG. 93. *The Trent Bore, near Gainsborough.*
This is locally known as the Aegir or Eagre.

much as 50 feet. On the Tsien Tang, a river near Shanghai, the bore has been known to reach a height of over 20 feet.

As has already been indicated, the action of tides in a shallow sea may produce strong currents, but these

tidal streams must **not** be confused with the tides themselves. The currents set now this way, now that according as the tide is ebbing or flowing. The ebb-stream may however continue to run for some little time after low water has been reached, and similarly the flood stream does not usually cease at the moment of high tide. There is a good example of an alternating tidal race in the Pentland Firth, between the mainland of Scotland and the Orkneys. The current here runs at a rate of from six to ten knots, and this makes the channel dangerous for shipping. **Whirlpools**, such as the famous Maelstrom on the coast of Norway, are often found where tidal currents mingle off coasts which have an irregular outline or are fringed with islands.

PROBLEMS AND EXERCISES

1. Which of the following would you expect to be the saltier :

(a) The South Atlantic on the Tropic of Capricorn, or the South Atlantic on latitude 60° S. ? (b) The East Pacific or the West Atlantic ? (c) The Sea of Galilee or the Dead Sea ? Give your reasons in each case.

2. Speaking generally, the oceans north of the Equator show a circulation as if the water had been stirred in the direction of the hands of a watch, and those south of the Equator show an opposite circulation.

Describe the currents of the Atlantic Ocean and show how far they are in accordance with the above statement. Illustrate by a sketch-map and indicate on it :

(a) a warm current ; (b) a cold current.

(Oxf. Jun. Local, 1910.)

3. Describe the route usually followed by sailing-ships on the voyage from England to India. Point out the relation of the different parts of the course to prevailing winds and currents.

(Oxf. Sen. Local, 1909.)

4. Distinguish carefully between waves, tides, drift-currents and stream-currents.

5. The hours of high and low water at a seaport, and the difference of level between them, vary from day to day. Give a general account of the changes which take place.

Explain why there is a difference in the rise and fall of the tides on the same day in the Bristol Channel and the Gulf of Genoa. (Oxf. Sen. Local, 1908.)

6. Atlantic tides come from the south ; Mediterranean tides from the east. Why is this ?

7. Estimate shortly the value of the tides to mankind.

LIST OF BOOKS AND APPARATUS

THE following are a few inexpensive **books** which deal more fully with the topics touched upon in this volume, and which might well be added to a School Library :

Maps: How they are made; how to read them. Dickson.
(Bacon, 6d.)

Maps and Map-Drawing. Elderton. (Macmillan, 1s.)

A Little Book on Map Projection. Adams (Philip, 2s.)

Surveying. Richardson (Philip, 1s. 6d.)

Practical Geography. Unstead. (Oxf. Univ. Press, 2s. 6d.)

An Introduction to Practical Geography. Simmons and Richardson. (Macmillan, 3s. 6d.)

Navigation. Hall. (Jack, 6d.)

Ordnance Map Scales and Characteristics. (Ord. Survey, Southampton, 6d.)

Climatic Control. Bonacina. (Black, 2s.)

Our Weather. Fowler and Marriott (Dent, 1s.)

Climate and Weather. Dickson. (Williams and Norgate, 1s.)

Hints to Meteorological Observers. Marriott. (Stanford, 6d.)

Physical Geography for Schools. Bernard Smith. (Black, 3s. 6d.)

Geography, Structural and Physical. Gregory. (Blackie, 6s.)

The Earth's Beginning. Ball. (Cassell, 7s. 6d.)

The Science of the Stars. Maunder. (Jack, 6d.)

The Scientific Study of Scenery. Marr. (Methuen, 6s.)

The Ocean. Murray. (Williams and Norgate, 1s.)

Whitaker's Almanac (published yearly, 1s. and 2s. 6d.)

Climatic statistics are given in some school text-books, e.g.

Reynold's *Regional Geographies* (A. and C. Black) and

Wallis's *Geography of the World* (Macmillan).

The following **apparatus** will also prove useful :

Plane-Table and complete accessories. (Philip, £3 3s.)

Dumpy-level. (Philip, 15s.)

Model Theodolite. (Harris, £1 1s.)

Anglemeter. (F. E. Becker and Company, 17 Hatton Wall E.C., 3s. 6d.)

"*M. and L.*" *Altimeter.* (F. E. Becker and Co.)

Slate-Globe. (Philip, 17s. 6d. to £1 5s.)

Herbertson's Graphic Map-projection Apparatus. (Philip, £1 1s.)

Tellurian. (Philip, £1 4s. 6d.)

Improved School Orrery. (Philip, £3 13s. 6d.)

Set of Instruments for Weather Observations. (Philip, £1 15s.)

Set of Geological Specimens. (Philip, £1 5s.)

Smaller Set of Geological Specimens. (J. R. Gregory, 139 Fulham Road, S.W., 10s. 6d.)

[For further details as to apparatus consult the catalogues of Messrs. George Philip and Sons, 32 Fleet Street, E.C. : Messrs. Philip Harris and Company, Birmingham ; or any well-known instrument maker.]

Ordnance Survey Maps are supplied at cheap rates to teachers who order large quantities. Apply to the Director-General, Ordnance Survey, Southampton.

Bell's (Portugal Street, W.C.) *Aids for Reading Ordnance Survey Maps* (wall diagrams), sheets 1 and 2, are useful. Price, 5s. each.

The following geographical **pictures** may also be recommended :

Land-Form Pictures (coloured). W. and A. K. Johnston. Set of twelve mounted on cloth, 24s.

Geographical Pictures—Land Forms and how they are made. A. and C. Black. In packets of six, 6d. per packet.

Land-form Pictures (suitable for framing). Philip. Set of twenty, £1 1s.

Further **questions** on Physical Geography will be found in the Oxford and Cambridge Senior and Junior Local examination papers, published by Messrs. Relfe Bros., 6 Charterhouse Buildings, Aldersgate, E.C.

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